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HEAD-UP DISPLAYS: A LITERATURE REVIEW AND ANALYSIS WITH AN ANNO--ETC(U)
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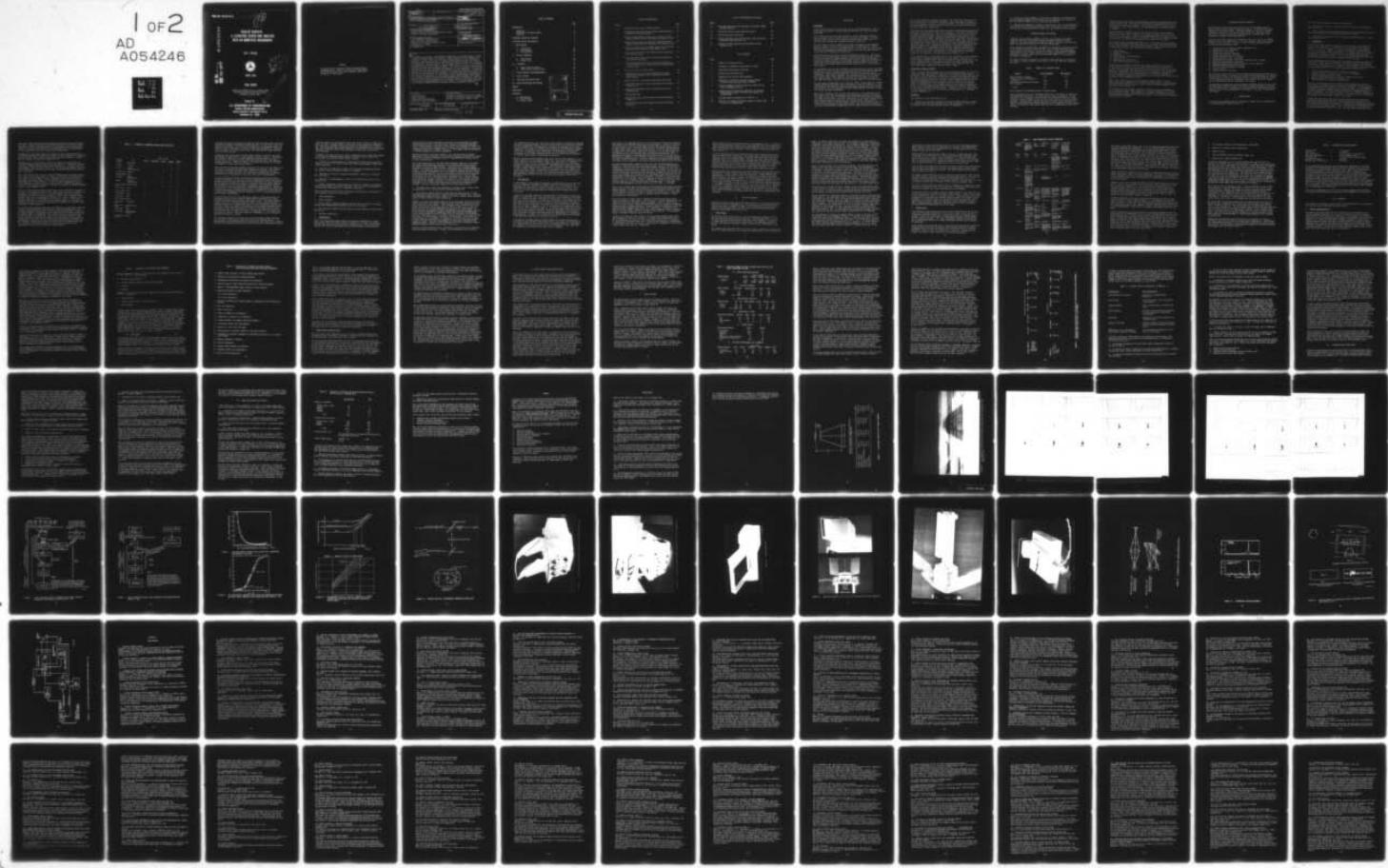
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HEAD-UP DISPLAYS: A LITERATURE REVIEW AND ANALYSIS WITH AN ANNOTATED BIBLIOGRAPHY

Jack J. Shrager



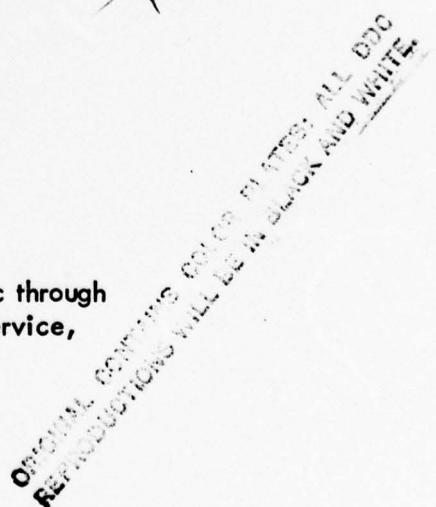
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FINAL REPORT

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16. Abstract This report is, in part, a bibliographic compilation of 293 publications relating to head-up displays (HUD's) for aircraft cockpit application and a summary of an evaluation of their contents in the areas of human factors, optical techniques, symbology, system concept, safety, simulation and flight test, and other factors or applications. The objective of this in-depth literature review is to determine the appropriate follow-up course of action in HUD's as it relates to civil aircraft application using current production HUD's. The results of a state-of-the-art HUD analysis which was also performed simultaneously is also summarised. It indicated that a HUD for the next generation can offer not only (1) resolution of illusionary problems, (2) reduction in pilot workload, (3) standardized cockpit procedures for both IFR and VFR operation, (4) reduction in intercrew dependency and coordination, but also has the potential for (5) terrain avoidance during takeoff and landing, (6) collision avoidance both in-flight and during ground operations, (7) taxi and takeoff clearance and conformation, (8) clearance delivery, (9) weather advisories, (10) efficient energy management and fuel economy, (11) noise abatement guidance, (12) prioritized annunciating and altering, and (13) pseudo-INS capability.			
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INTRODUCTION

BACKGROUND.

A pilot guides the path of his aircraft using two different worlds. This is true during all phases of flight operations and under all types of weather conditions.

One of these worlds is that seen through the cockpit windshield and other cockpit windows. This is often referred to as the "real world." The pilot sees this world with his eyes focused for long-distance viewing (i.e., at infinity) while looking over the glare shield or, "head up."

The other world is that presented by the flight instruments located approximately 30 inches in front of and below the pilot's head position. This is normally referred to as the "instrument world." In this case, the pilot's eyes must focus on instrument displays which are located below the glare shield at a relatively short distance, or "head down."

Neither world meets the pilot's total requirements successfully. Even under clear skies with unrestricted visibility, obtaining precise airspeed, pressure, altitude, and magnetic heading requires that the pilot shift his scanning pattern from the real world to the instrument world to obtain such information. Conversely, current regulations require some visual reference to the real world, even under highly restrictive weather conditions (i.e., see-to-land or see-to-taxi).

The instrument world was and is designed to provide the pilot with the necessary information for safe aircraft operations under restricted visibility conditions during those phases of aircraft operations which do not have the "see to" requirement. Since these instruments are located below the glare shield, the pilot's eyes look slightly downward. This has been referred to as a "head-down display (HDD)." Even with the introduction of the modern cathode ray tube (CRT) and digital electronic system, the HDD concept is still being used.

The most recent developments in the electronic HDD's are described in a Federal Aviation Administration (FAA) report published in June 1974, index No. 3. The replacement of the mechanical and electromechanical displays with the CRT HDD does not alter the close-in viewing distance (approximately 30 inches) to which the pilot's eyes must accommodate.

This visual transition from the real world (head up) to the instrument world (head down) places many psychological and physiological burdens on the pilot. One example is the visual transition from a localizer needle, which represents the runway (specifically, the runway centerline), to the lighted runway itself under minimum visibility conditions, and then returning to the localizer needle, should visual conditions change. Another is the refocusing of the eyes from short-range viewing to long-range viewing. The transition from head-up real world to head-down instrument world is a problem during both clear weather

and visually restrictive weather conditions. When additional problems such as heavy precipitation, fluctuations in ambient light, wind shear, and smog or haze are introduced, the pilot's workload increases. The workload is further increased because of the more frequent visual switching required between the two worlds under such conditions.

There have been many studies undertaken to resolve the problems associated with using these two independent worlds interchangeably. These may be grouped into two general classifications. One is the replacement of the real world with a reliable redundant facsimile using the instrument world (head down.) This system could use electronic attitude directors (EADI), electronic horizontal situation indicators (EHSI), low-light television systems (LLTV), infrared (IR), and electronic vertical situation indicators (EVSI). These used alone or in conjunction with conventional electromechanical flight instruments would be a total HDD system. Such a system was proposed for the United States supersonic transport (SST), and an experimental FAA system is currently installed in NASA's Boeing 737. A production version of such a system, which includes a HUD as part of the primary flight panel, has been developed for the United States Navy F18 aircraft. This approach to the problem was the principal subject of the previously referenced FAA report (index No. 3.)

At the opposite end of the spectrum would be the replacement of the instrument world with its facsimile superimposed on the real world. This would be a totally head-up display (HUD). This is the subject of this report, and it was also the general theme of a National Aeronautics and Space Administration (NASA) contractor's report published in January 1971, index No. 136. The latter NASA report reviewed all HUD work prior to 1969.

DEFINITION OF HEAD-UP DISPLAY.

A HUD is a device which presents all necessary information about the actual and desired situation of an aircraft under both visual and instrument weather conditions. This information is displayed in a way that the pilot can view both the natural external scene and its instrument facsimile simultaneously and in the same perspective, focused at infinity. Those parameters which are instrumentation representations of the real world should overlay the real world during the transition from the instrument world to the real world and back again. A HUD should be a total guidance system for the pilot, as opposed to an electric or electromechanical system which provides selective information such as pitch, attitude, and aiming point. Further, a total HUD would provide all the information necessary in the head-up presentation (i.e., airspeed, altitude, heading etc.).

OBJECTIVE.

The objectives of this undertaking are to:

1. Identify all available publications relating to HUD technology, systems, or concepts which have been published since 1969 (subsequent to those noted in index No. 136 of the bibliography attached as appendix A).

2. Survey the various segments of the aviation community to determine their current thinking and what active research has been applied, as it relates to HUD, with special emphasis on civil transport application.

3. Evaluate and summarize the results of objectives 1 and 2 in a manner which could be used as the basis of follow-on efforts in HUD as it relates to aviation safety, including simulation, flight test, and analysis of test results.

LITERATURE SEARCH AND OVERVIEW

A machine search was made of NASA's scientific and information documents (index No. 30) and the National Technical Information Services records (index No. 123) using as key words, Head-Up Displays, Advanced Electronic Displays, and Electronic Displays, for aircraft applications.

These computerized searches were supplemented by independent librarian searches of the technical libraries within the FAA. This included identifying and, where possible, reviewing all references contained in the reviewed documents regardless of source. These searches were further complemented by soliciting documented work done on HUD's by known interested members of the scientific and aviation communities.

The number of documents compiled, uncovered in these searches, and deemed, by this report's author, related to the intent in the first objective are shown in table 1.

TABLE 1. SUMMARY OF LITERATURE SEARCH

<u>Source</u>	<u>Total Documents</u>	<u>HUD Related</u>
NASA Scientific Documents	348	122
National Technical Information Services	152	* 57
FAA Libraries Referenced Documents	81	81
Other Sources	<u>33</u>	<u>33</u>
Totals	614	293

*Not contained in the NASA Scientific Documents Search

As was previously noted, the literature search was to be limited to those documents published since 1969. In establishing the control parameters for the analysis of the literature review, some of the publications noted in the NASA contractor's report (index No. 136) as well as the report itself were reviewed in depth. This was done to assure that this FAA report would supplement the NASA study and provide the desired continuity in HUD technology to the interested reader. In addition, those reports which related to helmet-mounted HUD's were excluded.

Table 1 indicates that there were 293 documents relating to HUD which have been published since 1969. They are listed in appendix A in alphabetical order by title and are sequentially numbered. The listing includes the author, date of publication, source, report number, and, when applicable, a critical abstract or summary.

These abstracts or summaries may not necessarily be that of the document's author, but rather a short version of its contents as they relate to the HUD objectives of this report. Some of the documents had neither a summary nor an abstract, but contained information considered to be worthy of summary notation. In these cases, an abstract was prepared by the author of this report.

An overview of the literature indicated that it was amenable to being grouped into general categories which were similar to, but not the same as, the chapters noted in the previously noted NASA report (index No. 136). The categories used in this report for the civil aviation application of HUD were:

- I. Human Factors
- II. Optical Techniques
- III. Symbology
- IV. System Concept and Mechanization
- V. Safety Factors
- VI. Simulation and Flight Tests
- VII. Other Applications and Factors

Appendix B is a listing of pertinent publications within each of the above seven categories by report title and index number assigned in appendix A. It should be noted that some publications may relate to more than one of these groups, and accordingly, they will appear in more than one of the related group listings. Conversely, some documents cannot be conveniently categorized in any of the defined groups and therefore will not be listed in appendix B. Multiple listings or omissions from appendix B are not indicative of the relative importance of the document's contents.

Based on the cursory overview of the documents noted in table 1, certain publications were considered to be of significant merit within a given category. Those publications which met that criteria, and are listed in appendix B, are identified by an asterisk (*).

As a further aid to the reader, an author's index is provided in appendix C. The associated document's index number, as it appears in appendix A, is listed after the author's name. This appendix also provides a convenient listing of those published individuals who have been recently, or are currently, interested in HUD for civil aviation.

LITERATURE REVIEW AND ANALYSIS

Following the review by title and abstract of the 614 documents noted in table 1, copies of 293 documents deemed pertinent to the HUD objectives were obtained for a detailed review. This was followed by a series of telephone conferences with many of the authors identified by the literature survey. This series of phone conversations expanded and/or clarified some of the information contained in the published text.

The review and phone conversations became the basis for a series of informal meetings with various segments of the aviation community that had an interest in HUD for civil aviation. Included in these informal meetings were HUD-oriented technical personnel from:

1. Airline Pilot's Association (ALPA), Washington, D.C.
2. Astronautics Corp., Wisconsin
3. Bendix Corp., New Jersey
4. Farrand Optical Corp., New York
5. General Electric Corp., New York
6. Hughes Electronics Corp., California
7. Kaiser Electronic Corp., California
8. Marconi-Elliott Avionics, Ltd. (E-A Industrial Corp.), Georgia
9. McDonnell Douglas Corp., California
10. McDonnell Electronics (formerly Conductron Corp.), Missouri
11. NASA Ames Research Center, California
12. Royal Aircraft Establishment, England
13. Sperry, Arizona
14. Thompson-CSF Inc., New York

The review and analysis which follows is based on information acquired from all three sources, namely (1) review of the 293 HUD-related documents, (2) telephone conversations with selective published authors of recent HUD technical reports, and (3) informal meetings and conferences with technical personnel engaged in current ongoing HUD research, development, and testing.

The analysis is divided into the seven groups identified earlier in this report and then further subdivided within each group as deemed necessary for clarity. Since the definition of a grouping may not necessarily be consistent with that normally used by some investigators, a definition of the group classification is provided.

I. HUMAN FACTORS

In this report, symbology which is influenced by human factors considerations is treated separately under section III.

The human factors considered under this section are:

1. Factors which relate to altering the pilot's workload, or "operational human factors,"
2. Those characteristics of displayed information which influence the pilot's sense of well-being, or "psychological human factors," and
3. Factors which deal with the pilot's physical characteristics, or "physiological human factors."

A. OPERATIONAL.

During clear weather daylight operations, the pilot has a three-dimensional world in color from which he derives much of the information necessary to guide the aircraft's flightpath. This is especially true in the terminal area (i.e., approach, landing, and takeoff). The pilot's workload includes not only the acquisition and comprehension of the visual cues, but also having the necessary freedom to exercise his skill and judgment in dealing with unrehearsed and unexpected events. The pilot is in a closed-loop, short-time response system with both raw and predictive information cues.

Aircraft instruments are an evolutionary development of monocular visual cues to provide monocular depth perception of selected parameters to replace the real world. A paper by Rolfe and Chappelow in 1971 (index No. 59) discusses this evolution development of the cockpit instrument system. The article points out that displays "must cater to human limitations in the ability to:

1. Detect stimuli outside a fairly restrictive repertoire,
2. Monitor processes, especially where events are infrequent,
3. Perform mathematical computations,
4. Retrieve large quantities of information rapidly and reliably,
5. Respond rapidly and reliably to stimuli, and
6. Perform repetitive activities consistently."

The article further notes that "the modern aircraft designer accepted the limitations of the human operator in acquiring information, and has provided first supplements and now substitutes for pilot's senses." In the design of the display system, development of the training syllabus, and establishment of operational procedures, these "human limitations" are considered, based on previous experience. It should be pointed out that the previous experience is almost exclusively in the use of round dial or vertical-scale-type instruments which evolved from the earlier systems of the 1930's.

A simulation study which evaluated pilot performance during an instrument approach with and without predictive display is contained in index No. 211. This report indicates that the results are "markedly and significantly superior" for displays with predictive information. The predictive information was similar to a trajectory (aiming point). One of the criteria of evaluating pilot performance was control column activity. The study indicated that the root

mean square (rms) stick activity decreased and "uncoupled aileron and elevator activity." Another simulation study in 1972 (index No. 212) showed a marked improvement in pilot performance using pictorial displays with guidance symbology. An earlier study (index No. 218) highlighted a similar improvement in the preservation of aircraft control with a simple HUD.

Although pilot performance apparently improves and his workload decreases as the displays approach total real world, there are some limitations to using only the real world. Table 2 shows the parameters that pilots employ for various phases of flight as identified in index No. 136.

Although most of the parameters required for terminal area operations are acquired through real-world visual cues, some cannot be. This is particularly true where absolute numerical values must be known (i.e., altitude, airspeed, and heading). Thus, even when flying on a clear day during daylight hours, the pilot's workload is influenced by the need to crosscheck the aircraft instrument flight panel.

Cues, both from the real world and flight instruments, and their priorities as they relate to the various phases of flight are discussed in the NASA contractor's report of 1971 (index No. 136). Though not noted in the 1971 report, priorities change with change in the flight phase, and so do the accuracy requirements of a given parameter. The use of a HUD to remove this partial or total dependency of using a portion of the instrument world is discussed in several of the documents contained in appendix A, including an Intrados Magazine article in 1976 (index No. 228).

Table 2 contains several parameters which may not be conveniently available to the pilot. Included in them are runway length, width, and slope. However, the knowledge of the numerical values of these parameters does not preclude the illusionary affects due to their variability. These visual illusions under daylight conditions are discussed in index No. 284. Several examples of illusionary affects due to runway geometry are shown in figure 1. This figure indicates that the pilot sees the same trapezoidal images of the runway, even though the distance to the runway may differ by 1,400 feet (A versus D) due to variations in runway geometry.

Several HUD system designs incorporate the capability and symbology to generate a runway visual scene using airport-related ground navigational aids (i.e., instrument landing system (ILS) or microwave landing system (MLS), (figure 2). This would present a standardized runway image focused at infinity which could be utilized under all conditions. The electronically generated scene would overlay the real world runway, but might not be consistent with the actual runway, (figure 2), since the electronic display generates a standardized runway geometry. The effects on the pilot due to these differences between the HUD instrument runway scene and the real world runway at breakout would have to be assessed. It should be noted that a HUD runway display could be programmed to correct for variations in runway geometry.

TABLE 2. A SUMMARY OF PARAMETERS VERSUS PHASE OF FLIGHT

<u>Parameter</u>	<u>Cue</u>	Phase of Flight				
		<u>Takeoff</u>	<u>Climb/Descent</u>	<u>Enroute</u>	<u>Approach</u>	<u>Landing</u>
Aimpoint	Runway Mark				X	X
Airspeed	Indicator	X	X		X	X
Altitude	Indicator Surface Object Size			X	X	X
Angle-of-Attack	Indicator	X	X	X	X	X
Flightpath Angle	Runway				X	
Groundspeed	Indicator Surface Objects			X	X	X
Heading	Indicator Ground Reference	X	X	X	X	X
Lateral Tracking Error	Ground Reference	X		X	X	X
Pitch Attitude	Horizon	X			X	X
Runway Altitude	Chart	X			X	X
Runway Length	Chart	X			X	X
Runway Slope	Chart	X				X
Runway Threshold	Runway				X	X
Runway Visual Aides	Chart Runway	X			X	X
Runway Visual Range	Ground Reference Radio	X			X	X
Runway Width	Chart				X	X
Surface Winds	Radio/Telephone Wind Sock	X			X	X
Vertical Tracking Error	Runway				X	X

The problem of visual illusions associated with approach lights under restricted visibility conditions is discussed in index No. 291. In the cases of both the whiteout and blackout, the pilot has great difficulty in determining where the runway is and, in some cases, is unable to make this determination. Precipitation may refract the lighted runway scene, thus shifting the viewed threshold from its actual position.

In index No. 291, the authors show pictorially (figure 3) the view the pilot sees during the simulation of a night approach aircraft incident. This article describes how a HUD and its related symbology would have shown the pilot a true picture of his flightpath and would have forewarned him of the impending incident (figure 4). Frame 7 of figure 4 shows that the aircraft's aim point, (red wedges) is toward the approach lights.

There are other illusionary problems relating to the real world that present the pilot with an increased workload during approach and landing. These include the whiteout (snow-covered runway and a clouded sky background), blackout (blending of the dimly visible or lit runway with a moonless sky and skyline), and the effects of refraction of the visual scene due to precipitation.

In most cases, HUD without an electronically generated runway should reduce the pilot's workload. In the case of using a standardized runway image and the problems associated with refraction due to precipitation, the pilot's workload may be adversely influenced by using electronically generated runway symbology. This would be due to the pilot having to determine if the difference between the two worlds is due to refraction or standardized image geometry. Resolution of this type of conflicting information would be accomplished by providing total situation information, including the ability to compensate for runway geometry or using other independently derived information, (i.e., ILS and inertial navigation position information).

A recent United States Air Force HUD report (index No. 209) dealing with the operational aspects (pilot workload) summarized the information of several documents and suggested that HUD has very limited value. The report evaluated a device which is a peripheral command indicator and not a see-through HUD. Adequate information for flightpath control was not incorporated, and the pilot was still required to transition from head-up to the standard head-down instrument world. Thus, this report discounts many of these characteristics which a true HUD would have incorporated into it. However, the report does point out that even this type of display did reduce the dependence of crew coordination on multipilot aircraft. The same reduction of dependence on crew coordination should be true with a true HUD.

The 1976 NASA conference on aircraft safety and operating problems (index No. 216) contained a presentation concerning the pilot's scanning behavior. The specific paper was the presentation of a testing tool which was used to correlate the pilot's eye-scanning pattern and the pilot's opinion on operational workload.

A HUD can present all the necessary visual cues noted in table 2. While this paper utilized a "standard" HDD, it does point out the operational workload for the pilot due to instrument scanning and should be applicable for use with a HUD. Two previously cited papers (index Nos. 212 and 218) noted the significant improvement which can result from providing the pilot with a pictorial or head-up display.

In summary, the areas which are or may be impacted by use of a HUD, with respect to the areas of operational human factors as denoted in the literature or uncovered in the state-of-the-art survey, include:

1. Potential for standardization in operational procedures during approach, landing, and takeoff for visual flight rules (VFR) and instrument flight rules (IFR) operations.
2. Reduction or elimination of many of the illusionary problems which have been factors in some aircraft accidents or incidents.
3. Reduction in the pilot's scanning requirements, especially in terminal area operations.
4. Reduction in interdependency on close crew coordination, again, in the terminal area.
5. Complete redundancy in monitoring all visual cues relating to flightpath control and guidance in multipilot aircraft. This is of major significance in low-visibility operations (i.e., categories II and III).

Other potential areas which could be influenced significantly, with respect to pilot workload, by use of a HUD include:

1. Energy management,
2. Noise abatement,
3. Visual midair collision avoidance, since the pilot or pilots are looking through their flight guidance display and at the real world.
4. IFR collision avoidance with the addition of data linked to traffic information, and
5. Ancillary annunciators.

B. PSYCHOLOGICAL.

Many of the publications which discuss the results of simulation or flight tests using a HUD often report a pilot's response of "a sense of well-being." This was true across the full spectrum of subject pilots. This includes both military and civilian, instrument-rated and noninstrument-qualified pilots,

pilots qualified in large multipiloted aircraft, pilots qualified in smaller single-piloted aircraft, and pilots with or without previous HUD experience. Such a broad subjective acceptance of HUD, even in the experimental stages, as a device which provides a greater sense of safety and well-being, is one of the continuing reasons for its support by pilots. This support has been documented in various periodicals as noted in appendix A.

Another previously cited paper (index No. 213) also discussed the marked improvement in pilot performance using pictorial displays, which may be a reflection of the positive psychological aspects of displays which simulate partial or total visual scenes.

One of the presentations of the 1975 AGARD conference (index No. 272) brought out several points which are important to both HDD and HUD electro-optical and digital electronic display systems. Through the use of modern digital avionics, it is possible that the pilot could suffer from "an embarrassment of riches." The digital processor and its accompanying displays have the ability to present so much information that it is possible to exceed the pilot's information processing capacity. The state-of-the-art survey, which was conducted in conjunction with the literature search, emphasized this. Tests by the United States Air Force under high-stress conditions, such as manual landings in low-visibility weather, indicated that some pilots could process pitch and bank steering bar commands adequately, but were not able to process altitude information. As a result, some pilots would descend below minimum descent altitude. This has an important implication in other areas, such as

1. The human factors which have indirectly or directly led to certain types of annunciators (i.e., Ground Proximity Warning Systems) and
2. The potential adverse affects of detracting the pilot from one totally consuming task to another without reducing the pilot's workload (i.e., required noise abatement flight profile or change in air traffic control (ATC) procedures during a critical phase of flight operations).

Index No. 272 notes that United States Air Force tests show that "if the pilot's channel capacity is overloaded, he declutters and processes information according to his own priority scheme." Thus, bringing visual information up to the display face does not insure that the pilot will be using it or in fact does use it any more than an acknowledgement by the pilot of a radio message is indicative that its meaning has been comprehended by the acknowledger. Several of the articles contained in appendix A, which were written by professional pilots, have stressed the need for simplicity and selectivity in information and form of HUD presentation. An earlier referenced publication (index No. 59) noted that the pilot's workload (and sense of well-being), includes not only the acquiring and comprehension of information, but also having the necessary freedom to exercise his skill and judgment in dealing with unrehearsed and unexpected events. Implied in that statement is the pilot receiving a comprehensible feedback from any action taken by the pilot.

During the state-of-the-art survey, the subject of the pilot's use of multiple cues was frequently discussed. A number of the parameters noted in table 2

are obtainable from more than one source, either directly or indirectly, through the pilot's mental processes. Thus, the pilot's sense of well-being is enhanced by this crosschecking. The HUD offers a technique by which many of the real world crosschecks could be simulated and therefore be available under instrument conditions. In addition, the workload under minimum visual conditions (VMC), as well as clear-weather flying conditions, can be enhanced by providing crosschecks to the flight instrument world with this information lying within the pilot's foveal field of view focused at infinity.

HUD has received favorable comments from pilots who have been exposed to it in either simulation or experimental flight tests. There was no documented test in which a HUD was used as the primary flight instrument panel in a transport category aircraft. In fact, current military application of production HUD's has been for single-pilot-type aircraft. (The United States Navy has recently decided to require HUD for future multipiloted aircraft.) This suggests that in such aircraft in which the workload is not shared, there is a human factor benefit from using a HUD. However, the specifics of such a benefit have not been documented. Needless to say, such an evaluation would have to first determine what and how visual cues are used, which are necessary, and which are ancillary.

C. PHYSIOLOGICAL.

A large segment of the classical definition of human factors lies in this area. One of the important physiological aspects would be the structure of the symbology, its size, flicker, resolution, color, etc., all of which are concerned with the parameters of vision as opposed to those of the eye. That portion which deals with symbology will be covered in a separate section of this report.

A paper by J. Lavernhe (index No. 198) evaluated the physiological differences between a standard HDD and a proposed HUD during cruise, approach, and landing phases of flight operations. The paper indicates that in the former, the eye must scan, thereby acquiring the necessary information in some sequential form. This requires the cerebral cortex to perform a multiple analysis, including some form of time correlation, before selecting the control inputs which would alter the aircraft's flightpath. The eye then detects the changes which have taken place. This is shown in figure 5. It should be noted that this analysis does not include cognitive switching between the instrument world and the real world under "see-to-land" conditions. Cognitive switching is the switching from one display to another and recognizing and comprehending the information being displayed. Further, the analysis does not reflect the process relating to multiple cues mentioned in the previous section.

In the case of the HUD, index No. 198 discusses how the eye can gather and correlate all the necessary information foveally and transfer this information in a simple format for the cerebral cortex to process (figure 6). Here again, the inclusion of the multiple cues (for a given parameter) is not shown, but the acquisition of the real world visual cues is assumed.

Early tests of an experimental HUD in a civil transport type aircraft (index No. 102) helped in the problems associated with space myopia. (This is the inability of the eyes to focus on points which are more than several meters away in an empty visual field.) This was demonstrated by the pilot's reported ability to pick up the runway lights sooner using the HUD. Since the HUD reduces the transmissivity by 25 percent, the earlier acquisition of the runway lights is the reverse of that to be expected when considering transmissivity only. Although not included in this experiment nor stated in any of the other documents noted in appendix A, this benefit of HUD could have the positive influence of visual collision avoidance. It further supports the benefits which HUD may have under visual illusionary conditions (see Operational Human Factors Section).

An earlier Douglas report (index No. 102) noted that the HUD eliminates the physical act of redirecting and refocusing the eyes, which has been previously alluded to. This not only reduces the physiological workload, but also the psychological workload as well. Though not reported in index No. 102, there is a time-saving by not having to refocus the eyes. The specific time saved by not having to go through this focusing and refocusing procedure would vary with the type of the display, its location, kind of information being displayed, and the physiological characteristics of the individual. Estimates of this time have varied from 3 to 11 seconds. These are subjective and are not explicitly identified in any of the documents cited in appendix A. Another time factor, which has been reported, is that associated with "attention gap." It was noted that the HUD "eliminated" this gap, which was on the order of 3 seconds.

Part of the "attention gap" may include the refocusing and redirection previously noted; however, this cannot be determined from the information reported in the Douglas document. Such a reduction in workload and decrease in time for cognizant recognition would have a positive influence in flight safety. This would be particularly true when operating in marginal weather conditions in which see-to-land was a requirement.

There are several articles noted in appendix A which discuss some of those factors relating to visual acuity. One of these is an article published in 1975 (index No. 108) which discussed display brightness. Figure 7, which is an extract from that report, shows the Weber-Fechner ratio of symbol to background brightness under daylight conditions. Against 3,000 millifootlamberts (mfl) the display should be approximately 60 mfl to be detectable. A general rule of thumb for minimum symbol brightness is that symbol brightness should be approximately 50 percent higher than the threshold of detectability. In the example chosen, the symbol brightness should be 90 mfl.

Figure 8, from index No. 108, reflects the relationship between visual acuity and brightness for rod and cone vision. The rods cannot distinguish colors per se, therefore, the curve for rod vision shown in figure 8 is a reflection of illumination detection levels only. Using the same abscissa for brightness, it can be seen that above -2.5 log L, visual acuity is dependent on the cone and varies linearly with the log of brightness.

Another area of visual acuity which should be highlighted is color. A Royal Aircraft Establishment paper (index No. 65) presented the effect the threshold of light intensity, $\log L_S$, versus display light intensity, $\log L_D$, for the colors white, red, yellow, green, and blue. This is shown in figure 9 as extracted from index No. 65.

It can be seen that red has the lowest threshold level throughout the entire range of display light intensities. This would suggest that red would be the best color for use in a single symbol color HUD or as the alarm or priority symbology color in a multicolored HUD. However, the cones, which are color sensitive, take over at higher levels of illumination, and the rods, which as previously noted are color blind, take over at the lower levels of illumination. Figure 9 indicates that as visual acuity is dominated by cone vision, the difference in detection as a function of symbol color decreases. In fact, figure 9 shows that the curves for blue, green, white, and yellow merge.

There have been other studies which have been conducted to evaluate the effects and benefits of color in modern and advanced aircraft cockpit displays and annunciators. An FAA report of June 1974 (index No. 3) indicated that the principal gain in the use of color was in discerning one symbol from another when the symbols overlapped or merged. The second principal advantage of color was to code priority on information (i.e., red for dangerous failure, etc.). A paper which discussed the use of color in connection with a HUD was presented at an (AGARD) conference in 1975 (index No. 33). None of the papers identified in appendix A assigned a significant gain to using real world color or multi-color to the synthesized scene or symbology with the exception of that noted before (merging symbols or alarm). As will be discussed in a later section of this report, the problem of merging, alarm and clutter can be resolved by other techniques.

II. OPTICAL TECHNIQUES

Within this section of the report are those portions of the optical system which generate the visible symbology which is projected by the optical system, the optical path used to transmit the image to the combiner lens, and the lens or optical device through which the pilot views the electronically generated symbology superimposed on the real world.

A. IMAGE SOURCE.

The CRT was, and as of this date is, the only technology currently in use in military production HUD's with the exception of helmet-mounted HUD's. It is also the only image producing device which has been evaluated in a simulator or flight tested for civil aviation application. The symbology can be produced by two different techniques, namely stroke writing, (calligraphic) and raster.

The stroke-writing technique used an electronic beam to energize a phosphorescent screen in a manner which is like stroking the symbology with a pen on a piece of

paper. The beam's luminescence is usually set manually to a level which is comfortable to the viewer, and the ratio of the symbol brightness to background brightness is maintained automatically. The background brightness in this case is the real world as viewed through the combiner system being used. The principal power requirement outside the anode voltage is that required to deflect the beam in the vertical and horizontal planes to write the symbology. These are usually internal deflection plates with relatively low-power requirements. Due to the slow writing-speed requirements (symbols only), the military specifications for symbol brightness (index No. 70) are attainable using a combiner lens with 70 to 80 percent transmittance and 30 to 20 percent reflectance. The use of such a combiner lens, while allowing sufficient symbol brightness for detection against a real world brightness of 10,000 fL, does reduce the real world light transmittance by 20 to 30 percent.

Raster is the technique used in television imaging. The beam sweeps the full width of the screen and, as it moves in lateral plane, the luminescence (brightness) of the beam is varied to create the symbology through variations in contrast. The beam successively repeats this process as it is incremented in the vertical plane creating the video image. The entire screen must be energized at various levels of brightness at a rate sufficiently repetitive to provide the necessary resolution and preclude flicker. This requires a much higher writing speed and a higher maximum brightness to allow for detection of the lower contrast portions of the symbology. The deflection of the beam is usually controlled by externally mounted coils which could require significantly more power than the deflection requirements of a stroke-writing system.

The techniques for stroke and raster imaging, as well as accomplishing either or both in black and white or color, are well known and predate the time frame of this report. It was therefore not unexpected that the literature search did not uncover any reports on the subject matter written after 1969.

Another technique for generating symbology is through the use of light-emitting diodes (LED's). This relatively recent technology has significantly lower power requirement than the CRT. Thus, the large power supplies and their associated heat dissipation equipment which are common to the CRT's are almost nonexistent when using LED's. The unique characteristics of the LED, such as small size, memory capability, and adaptability for use with digital avionics, makes them a candidate for application to a HUD. The only publication uncovered which discussed the use of LED's in a HUD application (other than helmet-mounted HUD's) was index No. 205. In this Marconi-Elliott proprietary paper, the LED's were employed to provide ancillary digital information for the "PERI-HUD."

The LED symbology is created in a manner similar to that of the wire service photographs used in the newspaper industry. The symbols are created by a series of closely spaced illuminated crystals. Thus, the failure of a single diode would not mean the loss of the total symbol, but rather would result in the symbol having a nonilluminated spot in its structure. A second characteristic that a LED HUD would provide is simple redundancy. Due to its small size and weight, dual LED's could be used with a two-position mirror in the

optical path, so that a catastrophic failure of the total LED image-producing system could be replaced by an independent dual system. A LED addressable matrix HUD has recently been proposed by one of the HUD manufacturers, with a planned flight test in late 1978.

Another miniature light-emitting system is the use of luminescent gas. This technology is often referred to as electroluminescence (EL), although LED's are technically also a form of electroluminescence. The technology has progressed from the high-voltage luminescent gases, (neon signs), to the development of low-voltage devices. Recent developments in the pocket digital computers and watches has seen the expanding use of EL in place of LED.

Both the LED's and luminescent gases have problems of washout under high ambient light conditions although there has been some experimental techniques under study in both fields which show promise. The washout problem is much greater in LED's than it is in EL's.

The liquid crystal technology offers an approach to miniaturized symbol generation which does not have the high ambient light washout problem. In fact, this technique produces increasing contrast with increasing light, since it is reflective, not light emitting. Accordingly, unless it is either back lit or has an auxiliary light source, it washes out with decreasing ambient light.

All three of the miniaturized systems offer the capability of generating colored symbology, although none offer the possibility of reproducing real world color such as that possible with raster-generated CRT color displays.

An in-house study by the Douglas Aircraft Company (index No. 62) summarized the various image sources and their pertinent characteristics. Table 3 is an extract of the information as shown in the Douglas report. This same report notes that an impetus for considering these modern display concepts, such as HUD, is the expanded use of digital avionics in both military and civil aviation. With relatively little effort, these microprocessors can be expanded to support HUD's, thereby making the HUD price competitive with the more conventional electromechanical displays which are in use today.

B. OPTICAL PATH.

The literature review and state-of the-art survey identified two optical techniques for presenting information to the pilot in a HUD. One is the use of collimating refraction optics with a collimating system and combiner glass or glasses. This is the evolutionary technique which developed from the World War II electronic gunsight. The other experimental systems use diffraction optics (holography) which uses a common holographic/combiner lens to present the symbology.

In the former case, refraction optics, there have been some new and innovative techniques which have been developed to provide miniaturization or compact packaging of the total optical system and/or increases in the vertical and horizontal fields of view. For purposes of clarity and continuity to the reader, the field of view is defined in the following paragraph.

TABLE 3. IMAGE GENERATING DISPLAY TECHNOLOGY

Display Type	Cathode Ray Tube CRT	Plasma Cell	Light-Emitting Diode LED	Liquid Crystal Display LCD	A.C. Electroluminescent EL
Characteristic					
Life Expectancy	7,000 to 20,000 hrs. Life depends on many variables such as phosphor characteris- tics and the lumi- nance level of the display.	5,000 to 50,000,000 hours.	10,000 to 1,000,000 hours.	10,000 to 30,000 hrs. (a.c. operation)	ML cell life varies inversely with fre- quency, but is inde- pendent of voltage both of which affect luminance. Typical life: 1,000 hours for decay to half level from initial luminance of 15 fL.
Drive Requirements	7,000 to 20,000 volts.	170 to 250 volts.	2 - 3 volts 3 - 600 milliwatts	6 - 15 volts a.c. 15 - 30 volts d.c. 0.01 - 4 microamps	50 - 500 volts.
Luminance	20 - 50 fL	25 - 50 fL	50 fL	LCD's do not emit light but act as light valves in passing reflected incident light or back- ground generated light (transmissive mode).	15 fL Brightness varies with voltage, fre- quency, and age.
Color	Red, green, blue (primaries)	Neon-Orange, red	Red, green, yellow	Many combinations of colors of numeric and background are available.	Blue, green, orange, pink.
Resolution	Typical: 30 to 125 lines per inch. The Northrop flat panel DIGISPLAY has a reso- lution of 50 dots per inch.	Gas panel display ~ GPD - up to 60 dots per inch.	Not yet suitable for large arrays	Not yet suitable for large arrays.	20-50 lines per inch.
Depth of Tube or Array	6 - 20 inches - The depth of CRT's approx- imates the face dia- meter except for very small tubes, which have greater propor- tional depth, and very large tubes, which have less pro- portional depth.	1/2 inch	1/2 inch In the transmissive mode, backlighting hardware will increase the depth.	1/2 inch	1/16 inch - 1 inch
Display Panel Size	1/2 inches - inches diameter. Larger sizes available on special order.	8 1/2 inches x 8 1/2 inches.	Not yet suitable for panel matrix use. LED's have a fast response but also have relatively large power requirements; e.g., a 1,000 x 1,000 array would require 5kW even if only 20 percent of the elements were lit.	Not yet suitable for large-scale panel matrix use because long switching times make sequential scanning difficult.	Display size is limited only by the capacity of production equip- ment. Individual char- acters as large as 10 inches in height have been produced. Slow switching times preclude EL use in large-scale panel matrices.
Switching Time	15 microsec.	20 microsec.	Nanosecond range.	Light scattering: 100 - 250 millisec. Field effect: 30 millisec.	100 - 200 millisec. when driven at 200 volts rms and 400 Hz.
Advantages	Can display large amounts of data. Flexible. Can display raw video, alpha- numeric or graphic data. Rugged wide range of viewing areas. Can be helmet- mounted or panel- mounted.	Flat panel. Low voltage (in relation to CRT). Thin profile.	Flat panel. Low voltage	Flat panel. Very low power. Low voltage.	Flat panel. Wide viewing angle. Rugged.
Disadvantages	Gray scale and full color range available. Can be used with many types of input devices; e.g., light pen, track ball.	To edge distor- tion.	Suitable for displays consisting of a relative- ly small number of ele- ments, such as alphanumeric indicators.	Great flexibility in char- acter size.	Limited operating temper- ature range: 0 - 60°C. Short life.
	Reliable. Can be ruggedized.	Suitable for dis- plays consisting of a relative- ly small number of ele- ments, such as alphanumeric indicators.	Suitable for displays con- sisting of a relatively small number of elements, such as alphanumeric indicators.	Not suitable for large- scale matrices.	High a.c. drive voltages.
	High voltage. Large physical size.	No gray scale currently avail- able.	Not yet suitable for large matrices.	In reflective mode, con- trast ratio is sharply reduced as viewing angle increases to 40°.	Not suitable for large- scale matrices which require rapid up-dat- ing.
	Edge distortion (with electrostatic deflec- tion).	No color currently available.	Major breakthroughs in drive circuitry, power requirements, and cost are needed before large- scale LED matrices will be competitive with con- ventional CRT's.	Limited character size.	Slow switching.

The field of view (FOV) relates only to the electronically generated and optical projected symbology and information. It is the pilot's ability to see this symbology as it's being superimposed upon the real world scene which is seen through the aircraft's windshield. The instantaneous field of view (IFOV) is the scene which the pilot sees with one or both eyes as he looks through the scene one would see when peering through a knothole in a fence. The closer one gets to the knothole, the larger the field of view. The proximity to the knothole in a refractive optics system is, in part, controlled by the size of the collimator lens. When seen by one eye, the field of view is circular, and when seen by both eyes, the field of view is like a figure eight laying on its side. The field of view without head movement is called the IFOV, and with head motion it is the total field of view (TFOV). Figure 10 shows the IFOV as a function of viewing distance from the exit pupil, (knothole), and collimator lens diameter for a conventional refractive optics system.

Figure 11 indicates the basic optical path for a conventional refractive optics system along with a sample of selected symbology. The full-scale representation of the instantaneous field of view represents the symbology. As seen using a 5-inch collimator lens, with the head position 18 inches from the focal point of the optical system.

Examples of some of the production HUD's in current use are shown in figures 12 and 13. Some of these systems used folded optics, since to be able to attain the compactness necessary to fit the available space, the optical path is folded back upon itself prior to its being projected to the combiner lens. Another technique used to meet space limitations, in this case the vertical limitation of the wind-shield and the pilot ejection clearance requirements, is the use of a dual combiner to get the desired vertical field of view. An example of this technique is shown in figure 13.

A different approach to the use of more than one combiner to achieve larger vertical fields of view is shown in figure 14. This concept uses four combiner surfaces in a solid truncated block of glass instead of two combiner surfaces separated by an air gap. This experimental technique brings the pilot's eye (exit pupil) closer to the combiner, thereby increasing the vertical field-of-view significantly. This system is scheduled to be flight tested in late 1978.

A paper presented at the Second Advanced Aircrew Display Symposium (index No. 205) describes an experimental refractive optics HUD system which reverses the normal HUD approach. A double lateral periscope is employed to view the real world. The CRT refractive optics symbology is combined with the real world which is projected to the combiner using reflective optics. This is shown in figure 15, where it can be seen that the real world in the "PERI-HUD," is viewed indirectly, and the CRT collimated symbology is viewed directly. This system allows the exit pupil to be positioned closer to the observer, thereby increasing the IFOV for a given exit optic (collimator lens) as shown in figure 10. Other advantages noted in index No. 205 include:

1. A 43-percent reduction in head movement to cover TFOV,
2. Reduction of undesired solar reflections,
3. Simpler optics,
4. Less encroachment into the instrument panel, and
5. Significantly lighter display unit.

A study was undertaken by one of the HUD manufacturers which had as its objective to determine what the limitations were to a HUD, not only for future aircraft, but also current modern jet aircraft. Having made that determination, they then developed a HUD concept which would meet these limitations. This system and its evolution are described in a June 1976 article (index No. 112). The "Mono-HUD" is a unit which is mounted approximately 4.8 inches in front of one of the pilot's eyes (figure 16). The refractive optics system presents the symbology which is superimposed on the real world to only one eye, while the other eye views the unobstructed real world. This technique is reported to provide the pilot with an IFOV of 21° in both the horizontal and vertical plane without degrading the pilot's view of the unobstructed real world or the conventional flight panel and control system. The human factors considerations in the use of such a HUD would require detailed evaluation.

Such a system could be designed so that it would be possible to use a single image generator to provide information to both the pilot and copilot by use of split mirrors. However, the system as currently designed uses a common symbol generator and independent CRT's and pilot display units (PDU).

A variation of this, though not stated in the paper would be the capability of redundancy for both pilot and copilot with an aircraft equipped with dual "Mono-HUD's." The PDU has a stowed position, if not desired for use, and a safety feature which allows it to collapse away from the pilot if necessary.

The "Micro-HUD" is another technique which has been developed to reduce the weight and space requirements of a refractive optics system. This system, which is shown in figure 17, uses fiber optics to bring the image from its source to the combiner lens. The experimental HUD is capable of being installed above the glare shield of existing aircraft; however, in its current configuration, it would conflict, to some degree, with the vertical cockpit cutoff angle. This system does provide the potential for retrofit and should offer great latitude to the application of various image generators with a minimum of modification.

Through use of diffraction optics (figure 18) it is possible to produce a relatively large field of view from a rather small image source. The hologram lens system being developed for an advanced HUD is described in index No. 154, 155, and 156. The lens system specifications designed for use with helium-neon laser image source are shown in table 4.

TABLE 4. HOLOGRAM LENS SPECIFICATIONS

Field of View	=	25° circular
Eye Relief	=	25 inches
Exit Pupil Size	=	3 inches high x 5 inches wide
Operating Wavelength	=	632.8 nanometers (nm)
Hologram Size	=	16 inches high x 16 inches wide
System Focal Length	=	9 inches
Minimum Optical Efficiency	=	80 percent

In the conventional refraction optics system, 70 to 80 percent of the light produced by the image generator passes through the combiner lens, and 20 to 30 percent is reflected toward the pilot's eyes. Most of the light produced by the image generator in the diffraction system (80 to 90 percent) is reflected toward the pilot's eyes (figure 18). This is possible without obscuring the real world, because hologram's efficiency varies with wavelength as shown in figure 19. Thus, all except a very narrow portion of the light spectrum can pass through the holographic combiner lens. The exit pupil (knothole) of this system, which is 22 inches from the combiner lens, is approximately at the pilot's eye distance from the lens. Therefore, it is possible to have a very large IFOV for a relatively small image source (20° vertically and 35° horizontally), with symbol brightness greater than 5,000 fL, and a combiner with a transmissivity of 90 percent.

While still experimental, the use of this technique suggests the possibility of designing the holographic lens system into the windshield of the aircraft.

III. SYMBOLOLOGY

This section of the report covers not only the characterization of the symbols, but also the control laws governing symbol motion.

A. SYMBOL CHARACTERIZATION.

The military has been using some form of HUD since its introduction as an optical gunsight in World War II. The evolution from the relatively simple application to today's multipurpose HUD led to the development of a military specification for optically generated displays. MIL-STD-884C, dated April 1975, (index No. 70) covers the wide range of symbology necessary to perform all phases of military flight operations including takeoff and landing. Notwithstanding this, a study by the Naval Air Development Center in December 1975 (index No. 140) noted the wide variations in symbology actually being employed in production HUD's. An evaluation of these deviations suggests that, in most cases, they were evolutionary and not revolutionary.

In the majority, especially in those related to military operations only, the symbology was modified to meet new requirement or to eliminate confusion. A paper presented in a recent AGARD lecture series (index No. 272) noted an example of this. It discussed the importance of considering the context in which the symbology is used as well as its form. Two examples of this are shown in figure 20. Figure 20A illustrates the interpretation of a symbol in illustrative context, and figure 20B, an example of information in verbal context. Both of these examples, which were presented in index No. 272, could have been a factor in the deviations from the optical symbology specifications noted in index No. 70. During the state-of-the-art survey, it was determined that the United States Air Force was in the process of preparing a revision to MIL-STD-884C. In addition, the Society of Automotive Engineers (SAE) committee on aircraft instruments (A-4 Committee) is in the process of looking into the preparation of minimum aviation standards for CRT displays when used for aircraft control and guidance. To what extent, if any, the SAE A-4 committee will have on standards for symbology is unknown at this time.

While much of the deviation from the military specification was based on changing requirements, there were others which were based on feedback from the user--namely, pilots. One of the leading proponent organizations which has supported the need to consider the potential safety aspects of a HUD in civil aviation is the Airline Pilot's Association, ALPA. Appendix A contains many articles which have been written by professional pilots concerning HUD and HUD symbology. The most recent recommendations for HUD symbology by a member of the All-Weather Flying Committee of ALPA is contained in index No. 159. In this document, the rationale behind each recommended parameter and its related symbol is discussed. The primary task of a HUD, as defined in this article, is to "improve safety during approach." As will be discussed in a later section of this report, the majority of air carrier type accidents occur during approach and landing. The parameters identified in the February 1977 ALPA article (index No. 159) are shown in table 5.

The article further suggests the possibility of prioritizing the symbology as a function of phase of flight to reduce clutter and enhance information transfer to the pilot. It should be noted that ALPA uses HUD as an adjunct to a HDD and not as a replacement of HDD.

The United States Air Force sponsored a major study dealing with the subject of symbology as it relates to flight control, flight control systems, navigation, pilot monitoring, etc. This contractor's report (Index No. 14) presents the analysis of 1,178 technical documents dealing with this specific subject. Shown in table 6 are 21 mutually exclusive display design variables which must be considered in display design.

These above-noted documents and comments highlight the fact that the subject of HUD symbology has not been resolved, particularly for civil aviation application, although there is considerable information upon which initial decisions are possible.

TABLE 5. SUGGESTED CIVIL AIRCRAFT HUD PARAMETERS

Control Parameters: (Aircraft status and rates plus feedback of the effect of control inputs)

1. Attitude (pitch and roll)
2. Aircraft Heading (numerical and textured horizon)
3. Airspeed
4. Altitude

Guidance: (Aircraft position fixing, comparison with desired position and rate of closure)

5. Runway Heading
6. Deviation with respect to navigational aid
7. Flare Guidance

Another factor, which was previously alluded to under the Human Factors section of this report, is the symbol brightness with respect to ambient light levels. The most recent HUD procurement specifications for the FL8 aircraft (index No. 92) define the maximum background (ambient light) lighting as 10,000 fL. This is approximately the light produced by the sun's reflection from the top of a white cloud. This is the accepted criterion for most military HUD's. However, a United States Air Force report in 1976 (index No. 240) cited that a common complaint of the subject pilots was the problem associated with variations in background lighting. The principal complaints were in the area of high ambient light (approaching, but not in excess of, 10,000 fL). The minimum contrast ratio (CR) deemed acceptable for the latest military HUD's is 1.2 over the entire viewing area. This is the ratio of the symbol's brightness (bs) to ambient light brightness (ba), as shown in equation 1.

$$CR = \left[\frac{bs}{ba} \right] + ba \quad (1)$$

CRT stroke-writing HUD's do meet these requirements, but at the cost of relatively high-power requirements (70 to 80 percent of emitted light passes through conventional refractive optics systems). In the case of a diffraction optics system, symbol brightness of 5,000 fL is readily attainable at very low power. Thus, a contrast ratio of 1.5 or greater is achievable with the hologram.

Referring back to a statement in the February 1977 ALPA article (index No. 159), the use of a prioritization of information as a function of the phase of operations is worthy of some expansion. This technique would serve to reduce clutter, which is most important in the application of the smaller suggested HUD designs.

TABLE 6. MINIMUM SET OF MUTUALLY EXCLUSIVE DISPLAY DESIGN/VARIABLES IMPACTING UPON DESIGN TRADEOFFS

- 1 - Ambient light intensity in which displays must operate.
- 2 - Reflection coefficients of display material.
- 3 - Transmission coefficients of display face materials.
- 4 - Required range of light emission intensities of emitting elements.
- 5 - Number of distinguishable light intensity levels required.
- 6 - Required uniformity of light emissions:
 - (a) at high intensities
 - (b) at low intensities
- 7 - Allowable tolerances for light intensity, transmissivity and reflectivity factors.
- 8 - Color of background.
- 9 - Color of emitters.
- 10 - Shape of symbols to be displayed.
- 11 - Dimensions of symbols to be displayed.
- 12 - Symbol placement and dynamic interrelationships.
- 13 - Information update rate requirements.
- 14 - Emitter (or spot) size and shape.
- 15 - Diffusiveness of boundary regions of individual emitters.
- 16 - Allowable (or required) frequency of alternating current (a.c.) or pulsed drive signal.
- 17 - Emitter placement or density.
- 18 - Size of background.
- 19 - Average light intensity of emitters.
- 20 - Display refresh rate requirements.
- 21 - Size of total display face.

such as the Mono-HUD, PERI-HUD, and Micro-HUD. It is also important in the case of the production HUD's now in use in the military and, to a much lesser degree, would be advantageous in the hologram HUD.

A second factor suggested by prioritization is the secondary cues referred to in the Human Factors section of this report, and the placing of symbology in a meaningful context. The versatility of digital avionics coupled with existing technology affords the opportunity to present meaningful information to the pilot (i.e., ILS localizer needle, synthetic runway, and runway apparent growth).

A third factor is the potential of combining selective annunciators into the display. Thus, an engine failure below critical speed and runway length would allow this information to override and perhaps replace all unnecessary displays such as airspeed altitude, pitch, etc. In the case of such a failure after reaching critical speed, such annunciation would be suppressed until reaching a safe altitude, after which this information would appear as an adjunct to other displayed information.

Before leaving the subject of symbology, there is another factor which should be discussed. Electronic information displays for aircraft flight control have, in a large part, been based on the electromechanical counterparts. This does not infer that such a basis is necessarily wrong. On the contrary, this has helped in their acceptance by the user. Another advantage is that the crosscheck between the electronic display and the standard instrument panel display has been simplified by this approach. However, the use of electronically produced representations of standard instruments should not be a limiting factor on symbology. To date, electronically displayed information has not yet been used as the primary and only display available to the pilot. The F18 aircraft will be the first such production aircraft with redundant primary electronic displays, both HDD and HUD.

The results of the literature review and state-of-the-art survey did not identify either previous work or current studies in symbol characterization in which there was not an assumption of potential cross-reference to standard instruments on their electronically generated equivalents.

B. SYMBOL MOTION (CONTROL LAWS).

While the shape, font, brightness, etc. are factors in symbol detection and recognition, their usefulness is dependent on knowing what they represent and how their movement is influenced by control inputs.

In the conventional HDD instruments, the pilot may and usually does have both raw and processed information. The bearing to a navigational aid is supplemented by the direction which the aircraft must be turned to fly over the aid. This, in turn, may be complemented by indicators which tell the pilot how much of a heading change is required and other predictive information necessary to get him on course. This type of information of the aircraft's horizontal situation is also required for the vertical situation. In addition to position guidance, the pilot needs energy guidance both potential and kinetic (i.e., airspeed,

thrust, altitude, and the rate of change in airspeed, thrust, and altitude). This information is then used by the pilot to develop the control inputs for guidance of the aircraft. This was demonstrated in recent wind shear encounter tests by both industry and Government investigators.

In the autopilot mode, the analytical solution of the particular phase of flight is accomplished electronically, using either analog or, more recently, digital techniques. The displayed information is used by the pilot to monitor the flightpath and status of the aircraft and its systems. The pilot is in a position to devote time to crosschecking, scanning, prior to making the required fine tuning of the control and guidance of the aircraft's systems or taking over manually. The precise interpretation (meaning) of a given symbol's motion, its accuracy (precision), ability to indicate rate of change (resolution), and repeatability determine its usefulness.

The manual mode use of displayed information is to provide the pilot with the necessary information by which the pilot's control inputs maintain or alter the aircraft's potential and/or kinetic energy state. What causes the symbol to move (forcing function), the smoothness of its motion (frequency response), and the jitter (damping) play an increasingly important role in high performance aircraft.

When consideration is given to using the HUD as the primary instrument for both IFR and VFR flight control and navigation, these terms all take on a new meaning. In the fifteenth symposium of the Society of Experimental Test Pilots (SETP) in 1971 (index No. 25), the various symbols used in tests with the Viggen aircraft were reviewed. The frequency response time, damping, and accuracy, as well as its forcing function, were discussed in a general sense.

The literature review described the general factors considered by the developers of HUD's with respect to the control laws employed. These descriptions were in the nature of the classical approaches (textbook) to the parameters which are required for flightpath control and guidance. However, the results of some simulator and flight tests indicated that the assumed forms of the algorithm including filtering, damping, and feedback did not produce expected results. In the state-of-the-art survey, it was discovered that the exact forms of the control laws used and the algorithms employed were proprietary information. Since scheduled commercial operations have different requirements than military operations, the algorithms used in a civil aviation HUD would not necessarily be the same as those used in the military HUD. Suffice to say, the driving functions of the symbols are of equal importance to the symbol form, illumination, etc. However, due to the previously noted proprietary nature of the control laws and algorithms used in the various proposed civil aviation HUD's, it was not possible to include such an evaluation in this report.

IV. SYSTEM CONCEPTS AND MECHANIZATION

The previous sections of this report have addressed some of the components of HUD's, such as image generators (CRT, LED) and optical paths (refractive, diffractive, fiber optics). The purpose of this section is to give the reader an overview of some of the HUD's currently in production, systems under development, and future systems which may be possible using known technology.

A block diagram of a HUD system proposed for an experimental program using the FAA's DC9 is shown in figure 21. This system was proposed by the airframe manufacturer for possible evaluation of HUD in June 1970 (index No. 141). The "display computer unit" is the symbol generator and is, in fact, a minicomputer with limited programmable features. Some of the production HUD systems have expanded the programmable capability of their symbol generators (PSG), and four of the experimental HUD's have symbol generators which are under total software control. In the latter case, this feature has been offered to the potential researcher for conducting HUD human factor tests and act as a proposed production prototype.

Also incorporated in the symbol generator are the analytical forcing functions, (algorithms) for the symbols which have been generated. Here too, the programmability varies from none to total. Included in the PSG may also be analog-to-digital convertors which allow the direct input of conventional aircraft sensor analog inputs to the PSG. Without this capability the aircraft sensors have to have a digital output which is compatible with the PSG or a separate A/D convertor.

The output of the PSG drives both the beam deflection unit (BDU), which positions the symbology, and the beam control unit (BCU), which drives the image generator assembly (IGA). The BCU includes an automatic brightness control (ABC) capability. This consists of an autobrightness sensor (some form of a photocell) which senses direct ambient light. This sensor is also used to detect the differential luminescence between the ambient light and that of the symbology.

One of the components of the IGA, namely, the image source, was discussed in some detail in section II of this report. Besides this unit, the IGA includes its related power supply and heat dissipation system. Some HUD designs, especially with relatively low power requirements like those for LED's, may only use a single power supply. It should be noted that in most HUD's, the IGA is considered part of the pilot's display unit (PDU). However, in this report it has been separated out to be consistent with the section on image generators. The optical system of the HUD has also been described in section II. One additional item worthy of noting at this time is that some of the military HUD's have incorporated either a photographic or video attachment at the optical assembly. There are several reports in appendix A which describe some of the work in this area. Included are the results of some of the recent United States Air Force efforts in this field (index No. 77) and related United States Navy efforts in this field (index No. 82).

The HUD also includes a pilot control unit (PCU). In the simplest of the HUD's, this consists of a power switch and manual brightness control. Most current production HUD's include a phase-of-operations selector, usually military mission oriented, and some include a landing mode. Those with a phase selection feature, preselect certain symbology and scaling. Most of the proposed HUD's for civil aviation application have symbology for approach and landing or takeoff. Very few PCU's incorporate selection for all phases of flight (i.e., taxi, takeoff, climb, cruise, descent, approach, and landing).

Figures 12 through 17 show some of the production and experimental HUD's which have been or can be considered for civil aviation usage. Most of those systems have been suggested or considered for future aircraft; however, some, like the PERI-HUD, Micro-HUD, Multicombiner-HUD, and Mono-HUD, may be adaptable to the more recent current aircraft designs.

V. SAFETY FACTORS

The military HUD's primary design criterion was weapon delivery. The use of the HUD for other purposes such as takeoff, cruise, approach, and landing were secondary, if considered at all. In the case of the civil use of HUD, the emphasis has been on the potential safety benefits.

Prior to examining the potential safety benefits of HUD, the problem they address should be stated. Table 7 is a tabulated summary of the National Transportation Board (NTSB) accident files from 1964 through 1975. The potential usage of HUD's in civil aviation has been primarily oriented toward its application to the larger air carrier type aircraft (over 12,500 pounds gross weight). Therefore, only the statistics shown in table 7 for the larger aircraft are used in the subsequent comments. However, it should be noted that most air taxi operations and other commercial operations do employ aircraft which weigh less than 12,500 pounds and that several of the experimental HUD's figures 14, 15, and 16, were designed for use in the smaller types of aircraft as well as the large jet transports.

Table 7A indicates that 50 percent of the large aircraft accidents occurred during takeoff or landing. Takeoff is defined as any accident which occurred between the start of the takeoff roll and the initial power reduction after lift off. Landing is defined as any accident which occurred between the initial approach fix (i.e., outer marker) and the end of the landing roll. The largest portion of these accidents was during landing.

Within this weight category, 1,076 accidents were air carrier accidents, and 498 were other than air carriers as shown in table 7B. Again, the application that HUD has to safety relates to all users of large aircraft and not just scheduled and nonscheduled air carriers.

TABLE 7. SELECTIVE SUMMARY OF NTSB ACCIDENT DATA 1964-1975 FOR
TOTAL FIXED-WING AIRCRAFT

A. Total Fixed Wing Aircraft

<u>Weight Category</u>	<u>Takeoff</u>	<u>Inflight</u>	<u>Phase of Flight Landing</u>	<u>Other</u>	<u>Total</u>
> 12,500 lb	277	669	628	254	1,828
< = 12,500 lb	9,538	14,273	26,313	3,574	53,698
Total	9,815	14,942	26,941	3,828	55,526

B. Aircraft Category

<u>Phase of Flight</u>	<u>Air Carrier</u>	<u>General Aviation</u>	<u>Other</u>	<u>Total</u>
Takeoff	175	29	73	277
Inflight	511	36	122	669
Landing	390	123	115	628
Total	1,076	188	310	1,574

C. Type Weather Condition

<u>Phase of Flight</u>	<u>VFR</u>	<u>IFR</u>	<u>Below Minimums</u>	<u>Other</u>	<u>Unknown</u>	<u>Total</u>
Takeoff	219	30	0	10	18	277
Inflight	466	116	N.A.	10	77	669
Landing	395	179	15	9	30	628
Total	1,080	325	15	29	125	1,574

D. Conditions of Light

<u>Type Weather Condition</u>	<u>Daylight</u>	<u>Night</u>	<u>Other</u>	<u>Unknown</u>	<u>Total</u>
VFR	791	286	0	3	1,080
IFR	183	141	0	1	325
Below Minimums	7	9	0	0	16
Other	82	39	21	11	153

E. Flight Phase

<u>Type Accident/Incident</u>	<u>Takeoff</u>	<u>Landing</u>
Hard Landing	N.A.	54
Overshoot	N.A.	67
Undershoot	N.A.	70
Stall	20	7
Uncontrolled Altitude Deviation	1	0
Collision with Ground Object	36	94
Other	220	336

F. Aircraft Gross Weight over 12,000 lb

<u>Aircraft Category</u>	<u>Injury Index</u>					<u>Total</u>
	<u>Fatal</u>	<u>Serious</u>	<u>Minor/None</u>	<u>Other</u>	<u>Unknown</u>	
Air Carrier	121	263	691	0	1	1,076
General Aviation	42	14	132	0	0	188
Other	81	21	208	0	0	310

Table 7C points out a most significant factor, 67 percent of all large aircraft accidents occurred during weather conditions which were at or above minimum visual conditions (VMC) which are often referred to by the lay person as VFR. Approximately 67 percent of the landing accidents in which the weather conditions were known happened at or above VMC and 88 percent of the takeoff accidents were also at or above VMC. The reason that this is considered a significant fact with respect to HUD is that most of the safety emphasis reported in the documents contained in appendix A stress the advantages HUD may have under very restricted visibility conditions.

Three areas in which HUD may be able to make a safety contribution under VMC weather conditions are blackouts or whiteouts, illusionary conditions, and wind shear. In the Human Factors section of this report, these hazardous areas were initially alluded to, but are worthy of further expansion.

There are several reports in appendix A, which deal with tests that have been conducted concerning the whiteout and blackout problem. Included among these reports are an RAE report in 1971 (index No. 96), a NASA study in 1972 (index No. 199), a United States Air Force contractor's report in 1973 (index No. 267), and a paper presented at the Flight Safety Foundation Air Safety Seminar in 1976 (index No. 132). These reports cover both simulation, flight test results, and, most interestingly, an operating airlines experience with head-up-type presentations. The reason for the distinction between display and presentation is that the latter system provides limited guidance, as opposed to a total guidance system, as defined in the early portion of this report. Notwithstanding this qualification, there were distinct improvements in overall pilot performance, reductions in pilot workload, and a decrease in deviations from desired flightpath with a HUD or HUD-type presentation, than there were with real world only or real world, plus standard HDD instrument world information.

In an early part of this report, there was reference to some of the illusionary problems facing the pilot (see figures 1 and 3). Index No. 291 describes in great detail the results of a simulation test in which the flightpath of an aircraft incident was duplicated using a flight simulator with a visual attachment. Figure 4 shows that, with a HUD, the pilot has advanced warning of the error in the flightpath and has the necessary guidance information to correct the aircraft flightpath.

At the time that this report is being written, tests are being completed to evaluate the potentials to safety that a HUD offers during severe low-altitude wind shear encounters. In one series of tests (index No. 291), the HUD was the most successful display of the four techniques used to minimize the change of either a missed approach or an unsuccessful approach (simulated accident). In each of the three areas of study, the HUD improved flightpath control, reduced touchdown dispersion, reduced pilot workload, decreased cockpit coordination or pilot to air traffic controller coordination, and reduced pilot anxiety.

In separate ongoing tests at one of the airframe manufacturers, (index No. 293), it was demonstrated that using a HUD enabled a series of subject pilots to

successfully negotiate an approach and landing during a simulated severe wind shear encounter. One of the HUD presentations was a minimum format considered necessary for assessing the use of flightpath angle (FPA) and potential flightpath angle (PFPA) during a wind-shear encounter. The tests indicated that, in summary, the eight highly experienced airline pilots rated the minimum HUD as a positive aid in coping with a wind-shear encounter. A further analysis of these tests indicated that part of their response was influenced by this novel form of displaying flightpath information and the specific value of the particular parameters displayed. However, there was an increasing positive acceptance of this minimum HUD with increasing exposure. After the third exposure, terms like "outstanding," "highly successful," "certainly an advantage," and "very useful" appeared in the pilot comments.

Table 7D shows that the majority, 78 percent of the VMC (VFR) accidents, occurred during daylight hours. This suggests that, contrary to the areas which have been previously stressed by a majority of the display studies, including HUD, there is a problem area during daylight VFR conditions which requires some positive action. A recent FAA low-altitude wind-shear accident analysis (reference FAA report FAA-RD-77-169) determined that there were approximately 25 large aircraft accidents in which low-altitude wind shear could have been present and, as such, a factor in the accident. Several of these accidents were under IFR conditions, and others occurred at night. Notwithstanding, the total of 25 is only 2 percent of the 1,080 accidents shown in table 7D (3 percent of the 791 VMC daylight). Referring to table 7E, it can be seen that 348 of the takeoff or landing accidents involve airspeed and or altitude control. This is the type of information the pilot obtains from the standard flight panel during both VFR and IFR operating conditions. Thus, during VFR, the pilot must divert his attention from the head-up world to the head-down instrument world to verify airspeed, altitude, and if desired, vertical speed, pitch, and heading. This diversion and time-sharing of the pilot's attention could have created an additional workload which, although not so identified in the accident files, could have been a contributing accident factor.

Table 8 is a summary of the visibility and precipitation conditions for selected landing accidents. The results show that for 15 of the 105 accidents in which the ILS was available, the visibility was 1/4 mile or less. This means that 90 accidents occurred during which time the visibility conditions were at or above category I requirements. This indicates that the major problem in IFR operations exists under weather conditions which are in excess of (better than) categories II and III weather conditions. As was true for VFR, the problems associated with IFR are not the highly restrictive weather (categories I and II).

A recent French study of world-wide accidents or incidents (index No. 13) extending over 10 years (1965 through 1974 inclusive) identified 150 cases of "human errors in the approach and landing phase." According to this report, a HUD would have improved the safety level in these commercial aircraft accidents or incidents to the extent of possibly preventing them. The accident types in which the report suggests safety gains are included in table 9.

Type of Approach	Visibility at the Time of the Accident					Unknown	Total
	0 - 1/4 MI	> 1/4 - 3/4 MI	> 3/4 - 2 MI	> 2 MI	Other		
ILS	15	27	24	32	1	6	105
ILS Backcourse	0	0	6	8	0	0	14
Precision Radar	0	1	2	3	0	0	6
Other NAV Aide	4	6	21	29	2	1	63
Other	51	74	0	884	42	335	1,386
						Total 1,574	

Visibility	Rain	Precipitation				Unknown	Total
		Rain Showers	Snow	Snow Showers	Stone		
0 - 1/4 MI	17	16	6	1	23	3	70
> 1/4 - 3/4 MI	10	5	10	6	22	1	55
> 3/4 - 2 MI	32	18	18	7	29	1	106
> 2 MI	71	53	15	5	748	60	956
Other	13	9	5	0	22	53	265
						Total 1,574	287

TABLE 6. VISIBILITY AND PRECIPITATION CONDITIONS FOR SELECTED NTSB LANDING ACCIDENTS,
AIRCRAFT GROSS WEIGHT OVER 12,500 POUNDS

A study by the United States Air Force in 1976 (index No. 240) indicated that the pilots generally reported that HUD's have the potential to be used as a primary flight reference system. The pilots also reported that there was a need to crosscheck with the standard HDD flight panel because of the lack of certain information in the HUD display. This is in agreement with an earlier comment in this report which indicated the limitations in the military HUD's and the need for a full HUD as opposed to a partial HUD.

TABLE 9. ACCIDENT TYPES AS CATEGORIZED IN INDEX NO. 13

<u>Accident Type</u>	<u>HUD Contributions</u>
Long landings and overruns	Reduction in touchdown point dispersion
Hard landing	Controlled descent rate and improve flare guidance
Bounced landing	Better stabilization of approach and flare
Short landings	Improved vertical guidance regardless of runway geometry or visibility restrictions
Wind shear	Improvement in vertical guidance and airspeed control
Descents below MDA	Reduced reliance of crew coordination and total system redundancy including pilots
Distraction due to annunciators with related cognizant switching	Total information displayed to both pilots at all times

An article published in 1970 (index No. 9) summed up the advantages of HUD following some earlier testing by an airframe manufacturer. As reported in this article they were:

1. It provides information for monitoring automatic approaches as well as for manual control.
2. It permits the pilot to perform all the required flight maneuvers, including navigational tasks, without disturbing his normal outside view.
3. It instills confidence in the pilots that the autoland system is functioning correctly.

4. It buys the pilot time, especially during the approach course, whereby it decreases his anxiety buildup and thus ensures a greater degree of pilot confidence both in his own ability and the total system.

Based on the results thus far discussed, to that list could be added:

5. It provides the necessary numerical data under VFR flight conditions without disturbing the pilot's normal outside view.

6. It minimizes, if not eliminates, the visual illusionary hazards due to variations in runway dimensions and grading, and aids in overcoming other visual illusionary hazards.

7. It eliminates the need of continuous scanning by being able to provide the necessary guidance and control information within the pilot's foveal vision without requiring refocusing of the eyes.

The importance of these seven factors is indirectly alluded to in a recent ALPA article of April 1977 (index No. 224). This article pointed out that the NTSB study of accidents during the time period of 1970-1975 showed "the pilot apparently was unable to assess, correctly, the flightpath or descent angle of his aircraft during the visual segment of the approach." A similar analysis was contained in a United States Air Force report (index No. 122). It stated that "a high percentage of all aircraft accidents, especially in high performance aircraft, are caused by pilot misjudgment of visual observations when making final approach." The Air Force report further indicated that the HUD system is to provide the pilot instrument information accuracy during the final phase of landing while the pilot is observing the real (visual) world.

A corollary paper which was presented at an ICAO meeting in 1974 (index No. 45) discussed the potential safety benefits of a HUD. It noted that a HUD would be helpful in detection of:

1. A "significant change in the angle at which the target zone is depressed below the horizontal," and

2. "Subtle changes in pitch or angle-of-attack" due to such things as a wind shear encounter. This was noted as being due to the limit of the unaided human ability to quickly detect changes in flightpath angle.

Some of the major advantages through the use of current state-of-the-art digital electronics, including HUD, were presented in a United States Naval Air Development Center paper (index No. 172). Some of the points noted which are applicable to HUD were:

1. Reduced pilot/aircrew workload,
2. Higher system reliability,
3. Increased flight instrument system performance, and
4. Reduced costs for the total cockpit.

This AIAA paper (index No. 172) assumed the use of a total state-of-the-art cockpit, including HUD as opposed to the standard HDD cockpit. The positive influence of HUD with respect to item 1 has already been covered. The increase in system reliability, (i.e., improvement in mean time between failures) by use of digital versus analog or electromechanical devices is well known and documented. Before leaving the subject of reliability, it is again noted that the use of a HUD during IFR takeoff and landing operations allows both pilots to use both the real world and instrument world simultaneously, thereby providing total redundancy in the multipiloted aircraft. This leads logically to the third item, increased flight instrument system performance, again, not the mechanization but the human factor. Since the pilot could and should use the HUD for all operations (IFR or VFR), there would be only one procedure which would be in use at all times. Every landing would be a HUD landing, thus greatly enhancing pilot proficiency and training. Lastly, referring again to the AIAA paper, this article cited that the cost of a state-of-the-art digital cockpit would be cost competitive to the cockpit in use today. In fact, some studies have shown that a total digital system with a HUD may in fact be less costly than today's system without a HUD.

A cursory review of the NTSB accident reports concerning air-carrier-type aircraft indicated several other areas where a HUD may offer safety benefits. One of these areas is the checklist and clearance. It is within the current state-of-the-art, especially with the use of LED's, to incorporate interlocking annunciation or simple display of checklist information without detracting from the ability of the pilot to taxi the aircraft. It is also within today's technology to transmit clearance information to the aircraft without the need of direct verbal information, and this too can be displayed to the pilot without detracting from his required visual tasks. The HUD also offers the capability of annunciating clearance for taxi and takeoff which may have precluded a recent major aircraft accident. HUD also offers the capability of priority annunciation or alarm during a particular phase of flight. Finally, a HUD does offer the opportunity, not only to reduce the dependency on crew coordination, but also to provide redundancy of information formerly requiring close crew coordination.

With the exception of the last of the preceding paragraphs on safety, the safety potentials of a HUD are applicable to today's production HUD's and today's modern jet aircraft. The latter paragraph relates to the safety potentials of the next generation of HUD's without any "breakthrough" requirement. As was pointed out in 1971 by Rolfe and Chappelow (index No. 59) a HUD provides the pilot with the freedom to react to the unrehearsed event.

VI. SIMULATION AND FLIGHT TESTS

Appendix A contains numerous articles which deal with simulation and flight tests of proposed HUD's for civil aviation usage. As was previously noted in earlier portions of this report, these tests were primarily oriented toward low visibility and the combined use of the HUD with standard HDD crosscheck.

One of these reports (index No. 276) proposed an approach to evaluate the safety contributions of a HUD for all-weather operations. It delineated the basis for choosing the display content, display format, design features, and properties of a HUD, quantitative and qualitative techniques for evaluating the performance using a HUD, and a proposed methodology for identifying the potential benefits of a HUD. In this one report can be found most of the techniques and procedures used by the majority of HUD experimentalists. The counterpoint to this was a comment in an earlier referenced United States Air Force letter report in August 1976 (index No. 240), which indicated that its author was not familiar with any programs in which a HUD was used as the primary instrument for takeoff, cruise, or approach and landing, especially the latter.

Thus, what were not found in the literature were documented tests of a total evaluation of the HUD concept. Such an evaluation should and would include:

1. A visual real-world referenced baseline flight profile with normally used HDD crosschecks (i.e., airspeed, altitude).
2. Repeat "1" above using HDD's with minimum visual conditions currently in use by operators of high performance or large nonmilitary-type aircraft.
3. Repeat "1" above using a total HUD with head-down flight panel crosschecks.
4. Repeat "1" above using only the HUD display.

It is only by developing such a program that the benefits and limitations of using a HUD can be determined. This is not to say that a HUD would not offer safety benefits under certain special conditions which have already been discussed; however, the magnitude of such benefits have been partially masked by the testing techniques used. Examples of the latter are tests in which a partial HUD was used as an adjunct to the conventional HDD or a see-through-type display. The results of such tests, which present selective guidance information to the pilot during VFR-type operations, were too limited in scope to provide definitive results. Tests should include representative accident flight profiles due to wind shear, night and day illusionary problems, cockpit coordination breakdown, alarms, and annunciations and should evaluate:

1. Control usage including both frequency and magnitude of movement,
2. Pilot scanning pattern (mainly for workload determination),
3. Deviations from desired flightpath, touchdown, and ground roll.
4. Required crew coordination, and
5. Flexibility in navigation and/or flightpath control with reduced or compromised display and/or aircraft systems.

In the opinion of the author, the literature suggests that the symbology used was strongly biased by those evaluating it; namely, experienced professional subject pilots. Needless to say, any pilot display must be tested and evaluated by the intended user. If a display differs radically from normal, one of several factors will influence the results such as:

1. Bias due to training and conditioning favoring the standard display as opposed to a radical display,
2. Personal bias of one form of information display versus another, and
3. Bias of one display concept over another. Examples of each of these were present in the literature which was reviewed and evaluated.

Many of the evaluations of a HUD used symbology and display symbology positions (location) that were very similar to conventional head-down symbology. Thus, the training time required to familiarize the randomly selected subject pilot was of short duration. This might afford the experiment a means of evaluating the gains by eliminating cognizant switching, but would not provide information concerning the advantages which might be attributable to using symbology approximating the real world.

The variations in symbology for any given parameter as reflected in index No. 70, is an example of the second point noted above. While admittedly some of the variations are due to field experience, a pilot trained in one form of symbology would be biased toward that symbology due to conditioning.

With the introduction of digital electronics and CRT's into some cockpits, pilots are being conditioned to HDD electronic displays. An earlier FAA report (index No. 3) alluded to this in its presentation of EADI representations of flight director information. Thus, in a split-panel aircraft, such as the F18 which uses both electronic HDD's and a HUD, the values gained by not having to switch from head-up to head-down or the value of a totally head-up display could be lost.

When considering the design and evaluation of a HUD for the next-generation aircraft, as opposed to tests designed with retrofit considerations as a major factor, the revolutionary approach to HUD symbology based on unbiased human factors studies should be the controlling element. Symbology and format of the display, head-up or head-down, should be based on ease of recognition and minimum, if any, specialized training or conditioning. Some earlier work by Stanley Roscoe at the University of Illinois was along these lines and showed some interesting results in the form and type of instrument presentations that unskilled general aviation pilots were most readily able to adapt to. These studies predate the reference time frame of this report, namely post-1969.

The review and analysis of the documents contained in appendix A, and the state-of-the-art survey indicated that part of the problem in the implementation of HUD's in large aircraft, including the military, is due to the limitations in the tests conducted to date which have not defined clearly and concisely the advantages and limitations of HUD. However, most of the documents cited in appendix A, as well as those which were reviewed and summarized in index No. 136, do suggest that a HUD should enhance flight safety.

The problem remains one of philosophy versus specifics and psychological versus practical. This emphasizes the importance of the development of a test program and test criteria which would resolve this issue, especially, but not necessarily limited to the next-generation transport category aircraft.

VII. OTHER APPLICATIONS AND FACTORS

A 1973 study by R. T. White (index No. 62) noted the following gains which could be attributed to a state-of-the-art display such as HUD. These include:

1. A reduction in the amount of displayed information as a function of the phase of flight (this could materially reduce the pilot's workload, especially during critical or emergency conditions).
2. Due to the inherent flexibility of computer-driven displays, it may be possible to design and utilize a more completely standardized cockpit.
3. Add-on features and options are also possible without extensive hardware modifications.
4. Such usage would increase general reliability (i.e., LED reliability estimates are as high as 10^6 hours).

A paper by Messrs. Hillman and Wilson (index No. 176) indicated, in tabular form, the expected benefit noted in "1" above by use of a CRT in lieu of conventional HDD. The table, as shown in the Hillman-Wilson paper, is reproduced in table 10.

The mean time between failures (MTBF) shown in table 10 refers only to the attitude and horizontal situation displays. If the other conventional displays of engine, hydraulics, etc. were also considered, the conventional MTBF would be less than 700 hours. If LED's were substituted for the CRT, the MTBF would approach 10^6 instead of 2 times 103.

The HUD offers the possibility not only of energy management, but also energy efficiency through the use of its related microprocessor. It is possible to display on the HUD the predictive flightpath which would allow the pilot to make the maximum use of the aircraft potential energy, particularly in the descent from cruise altitude. An expansion of this concept is its use in noise-abatement for takeoffs and landings.

With the digital processor required by a HUD, it is possible to provide the capability of transmitting, through a data link, traffic target information from the ATC computer to the aircraft processor. Since the display is focused at infinity, this target information would aid in attracting the pilot's attention to a potential traffic conflict. Other hazards, such as high terrain, can also be furnished through such a data link, thereby providing this information to aircraft without inertial navigation systems (INS). In fact, the data link in combination with the HUD can provide a pseudo-INS for such aircraft.

TABLE 10. REDUCTION IN DISPLAYS AND DISPLAY WEIGHT BY USING A CRT IN LIEU OF A STANDARD HDD

	<u>Conventional</u>	<u>CRT</u>
Number of displays:		
Flight (Capt. & F/O)	26	4
Engine	33	1
System	47	2
Standby	<u>4</u>	<u>10</u>
Total	<u>110</u>	<u>17</u>
Display area (sq. ins.):		
Flight (Capt. & F/O)	420	280
Engine	330	50
System	<u>1,370</u>	<u>90</u>
Total	<u>2,120</u>	<u>420</u>
Display weight (lb):	250	200
	not taking account of a significant reduction in wiring weight for CRT's.	
Approx. MTBF (hours):	ADI/HSI: 700 (only)	2,000

A study by the British Aircraft Corporation, index No. 84, highlighted some of the other potential benefits attainable through the use of advanced flight deck instruments in civil aircraft. These benefits would be applicable for both HDD and HUD concepts and included:

1. Improved crew/machine interface which should contribute to improved safety, reduced workload, and greater flexibility in operational procedures.
2. The acceptance of a two-crew flight deck for short/medium-haul aircraft, with a consequential reduction in direct operating costs. At the same time, it also offers the opportunity of using three-crew versions of the same aircraft at minimum additional costs and maximum efficiency.
3. A substantial decrease in the absolute number and types of instruments, giving a significant decrease in the cost of ownership to the aircraft operator.
4. Improved dispatch capability and greater tolerance to airborne failures, due to the flexibility of CRT (or LED) displays.

5. First cost and weight should be less than for a conventional (electro-mechanical) system.

6. Substantial reduction in installation design man-hours, aircraft wiring, and simpler instrument panels.

Most of the points highlighted in this September 1976 report have in fact been demonstrated in military aircraft which utilized these concepts, including HUD, in single-piloted aircraft. The complexity of these aircraft and the variety of their flight profiles are at least equal to, and in most cases greater than, those which are normally encountered in civil aviation.

Other potential uses of the HUD, some of which were previously noted, include:

1. Displayed taxi, takeoff, and landing clearances and/or alerts,
2. Changes in enroute clearances,
3. Prioritized annunciation alerts, and
4. Weather advisories including ATIS.

Many of the above additional potentials of a HUD are due to having a digital processor onboard and are not necessarily due to electro-optical display capability (since most HUD's include a microprocessor). However, the HUD provides this additional information display capability in the normal direction of the pilot's eyes under VFR conditions without compromising his field of view or requiring him to divert his attention from the task at hand.

SUMMARY

A research of the literature and state-of-the-art survey has identified or suggested areas in which a HUD may make significant contributions to flight safety. These contributions to safety are not limited to the IFR environment, but, to the contrary, would be primarily enhancing safety in the VFR world. These enhancements are achievable through the use of current HUD technology, using minimum and readily recognizable symbology.

Some of the prototype or experimental HUD systems were developed to meet the limitations of today's modern jet aircraft. These include, but are not limited to, the Mecure, Caravelle, DC8, DC9, DC10, B727, and Gulfstream II. Prototype HUD's have been, or will shortly be, flight tested in these aircraft. In addition, a limited HUD concept has been flown in a B747 and is in limited air carrier operational use in B737's, B727's, and C130's.

The state-of-the-art HUD for the next-generation aircraft can offer not only flightpath guidance and control for all phases of flight, but also has the potential for:

1. Terrain avoidance,
2. Collision avoidance,
3. Taxi and takeoff affirmative clearance,
4. Annunciation and alerting,
5. Clearance delivery,
6. Weather advisories,
7. Efficient energy management,
8. Noise abatement guidance, and
9. Pseudo-INS capability.

The reliability of HUD's surpasses that of conventional HDD's. On a total cockpit basis, a HUD system would be cost competitive, if not less expensive, than the modern HDD's. This would be particularly true in those aircraft scheduled to have INS onboard.

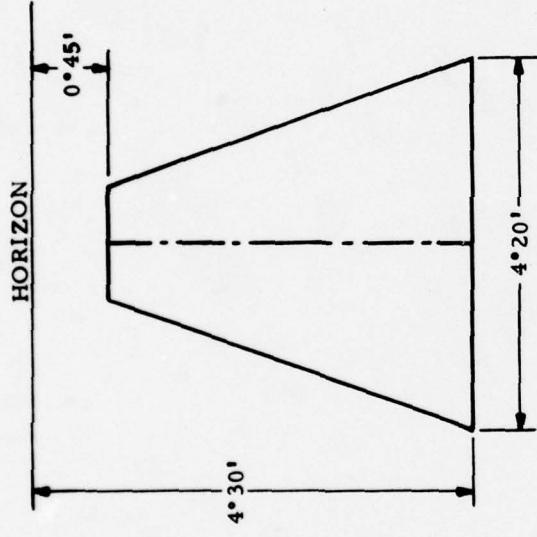
The use of a HUD would reduce current pilot workload and crew member inter-dependency. This could also lead to a reduction in crew size for some aircraft types without compromising safety or improvement in flight deck workload.

CONCLUSIONS

Based on the results of this study, it is concluded that:

1. A HUD offers a means of reducing the operational workload of a pilot under both IFR and VFR conditions. This reduction in workload would apply to all flight deck personnel and could impact crew requirements for certain types of aircraft.
2. A HUD provides a means of achieving true redundancy in multipiloted aircraft regarding information for navigation, flightpath control, collision avoidance, alert and warning systems, and mandatory crew coordination (i.e., both pilots are simultaneously monitoring the instrument world, the real world, and prioritized alerting and annunciating systems).
3. Certain of the visual illusionary problems encountered in normal terminal area operations can be compensated for or eliminated through the use of a HUD, (i.e., whiteout, blackout, and erroneous vertical cues).
4. A HUD offers a technique by which the interdependance of crew coordination and communications could be reduced during critical phases of flight without compromising flight safety.
5. HUD's have the potential for increasing cockpit flight instrumentation reliability by at least one order of magnitude using CRT technology when used in lieu of mechanical or electromechanical instruments. The reliability can be significantly increased even further by using LED's and EL technology instead of CRT's.
6. There are several production military HUD's which may be compatible for use in future air-carrier-type aircraft. None of these HUD's which were produced for the military can be retrofitted into most of today's modern air-carrier jet aircraft fleet without extensive modification.
7. There are several experimental HUD's which may be adaptable to the current fleet of air-carrier-type aircraft. At least one of these systems was designed with the constraints of being retrofittable into existing air-taxi and air-carrier-type aircraft. However, none of these proposed HUD's has been evaluated to the extent necessary for such broad consideration or application.
8. A HUD system, with its related digital electronics, has proved to be cost effective in military application and has been predicted to be equally cost effective in civil application for future civil air-transport-type aircraft.
9. The advantages and limitation of a HUD when used as the primary flight display in commercial aircraft operations for all phases of flight have not been defined and documented. This applies both to the safety and economic aspects of a HUD system.

10. Minimum performance and safety standards for a HUD system to be used in civil aviation have not been developed. However, the military have developed specifications for HUD's in single-piloted aircraft. In addition, the military is developing specifications for multipiloted aircraft HUD's.



RUNWAY GEOMETRY AS SEEN UNDER EACH
OF THE FOLLOWING CONDITIONS

	A	B	C	D
RUNWAY LENGTH	6,000 FT	8,000 FT	10,000 FT	10,000 FT
RUNWAY WIDTH	100 FT	150 FT	150 FT	200 FT
DISTANCE TO RUNWAY	1,300 FT	2,000 FT	2,000 FT	2,700 FT
ALTITUDE	100 FT	130 FT	157 FT	210 FT
GLIDE SLOPE	2 1/2°	2 1/2°	3°	3 1/4°

77-42-1

FIGURE 1. ILLUSIONARY EFFECTS DUE TO RUNWAY GEOMETRY

77-42-21

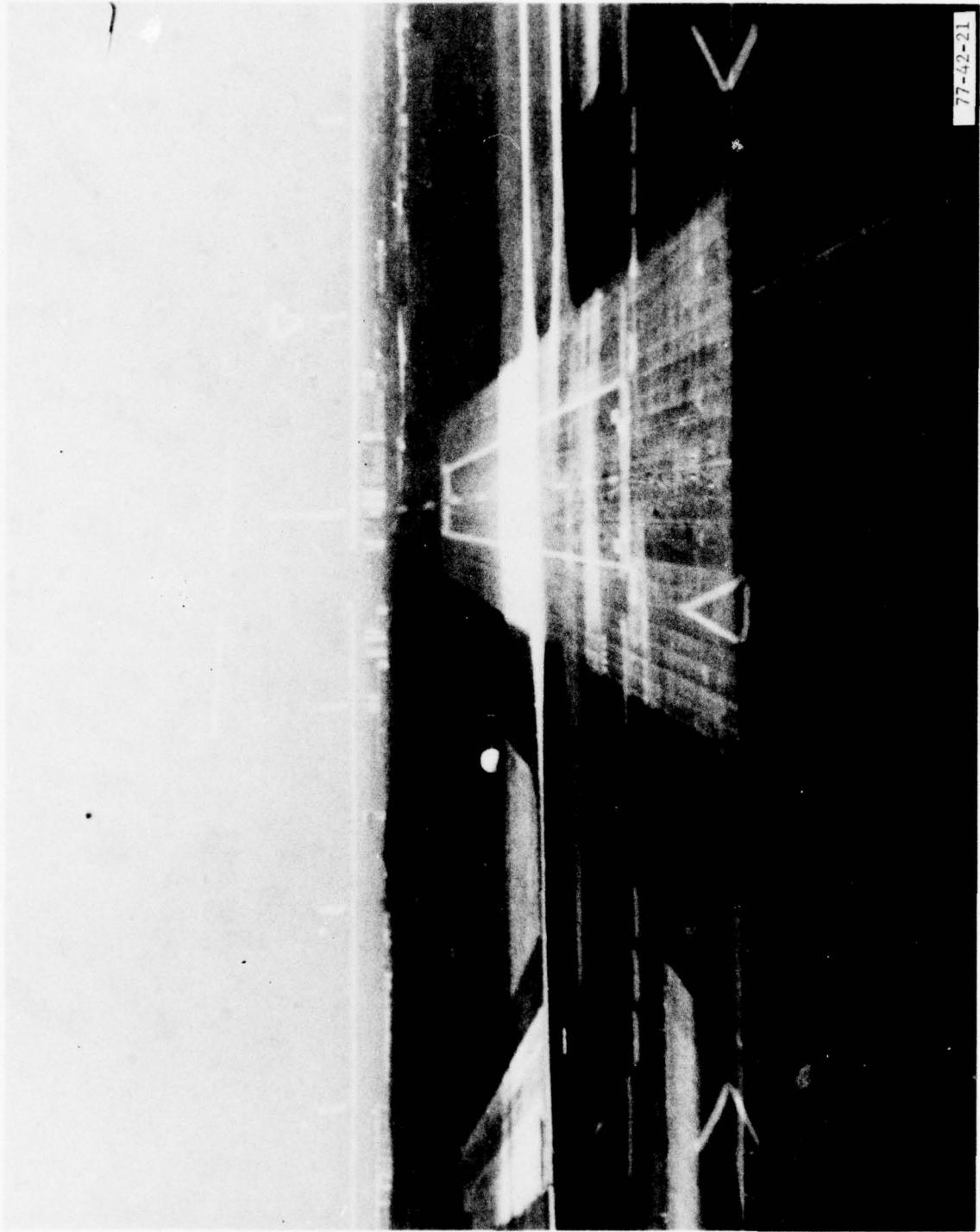


FIGURE 2. HUD SYMBOLS INCLUDING RUNWAY FACSIMILE (REPRINTED WITH PERMISSION FROM INDEX No. 291

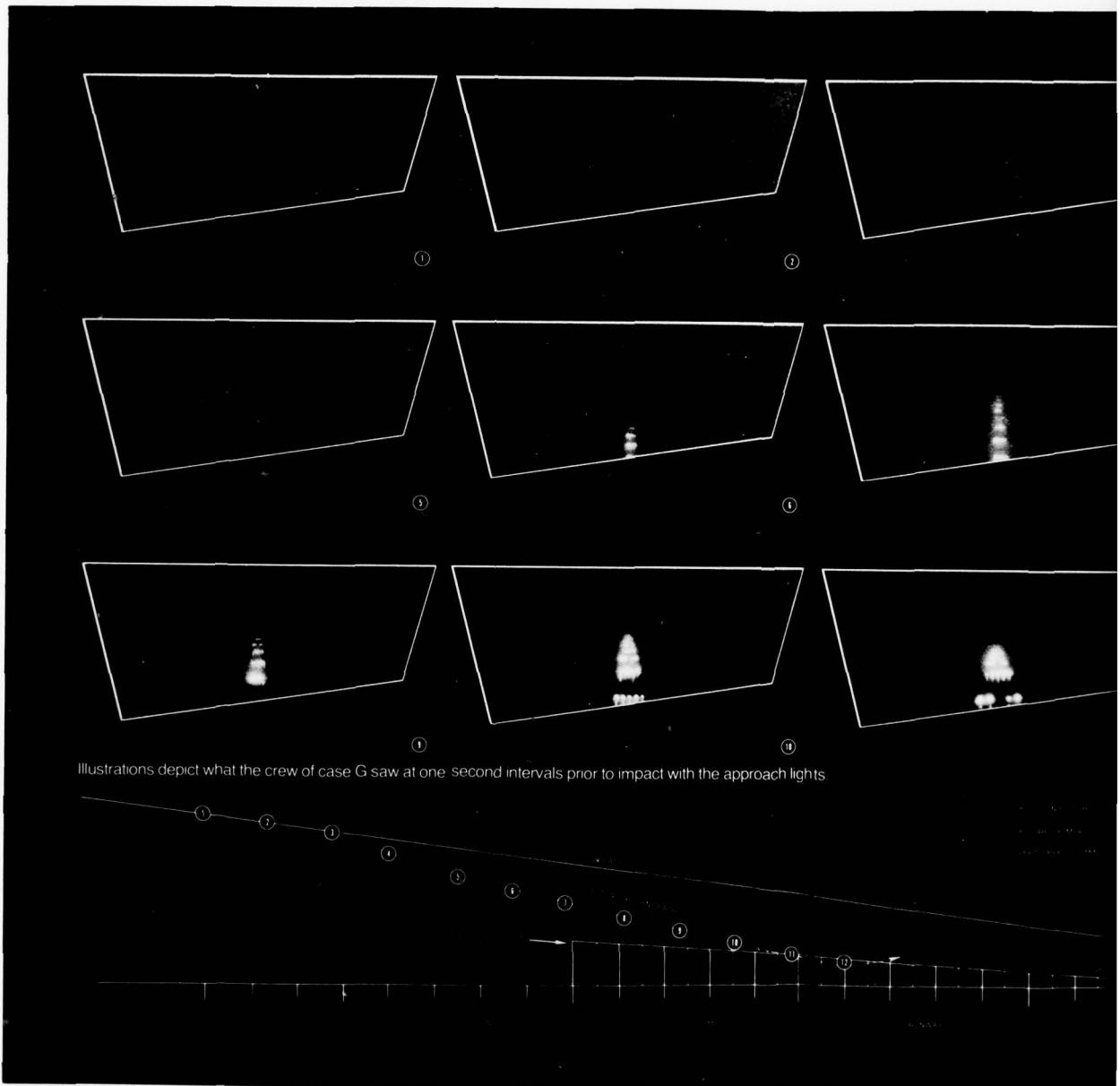
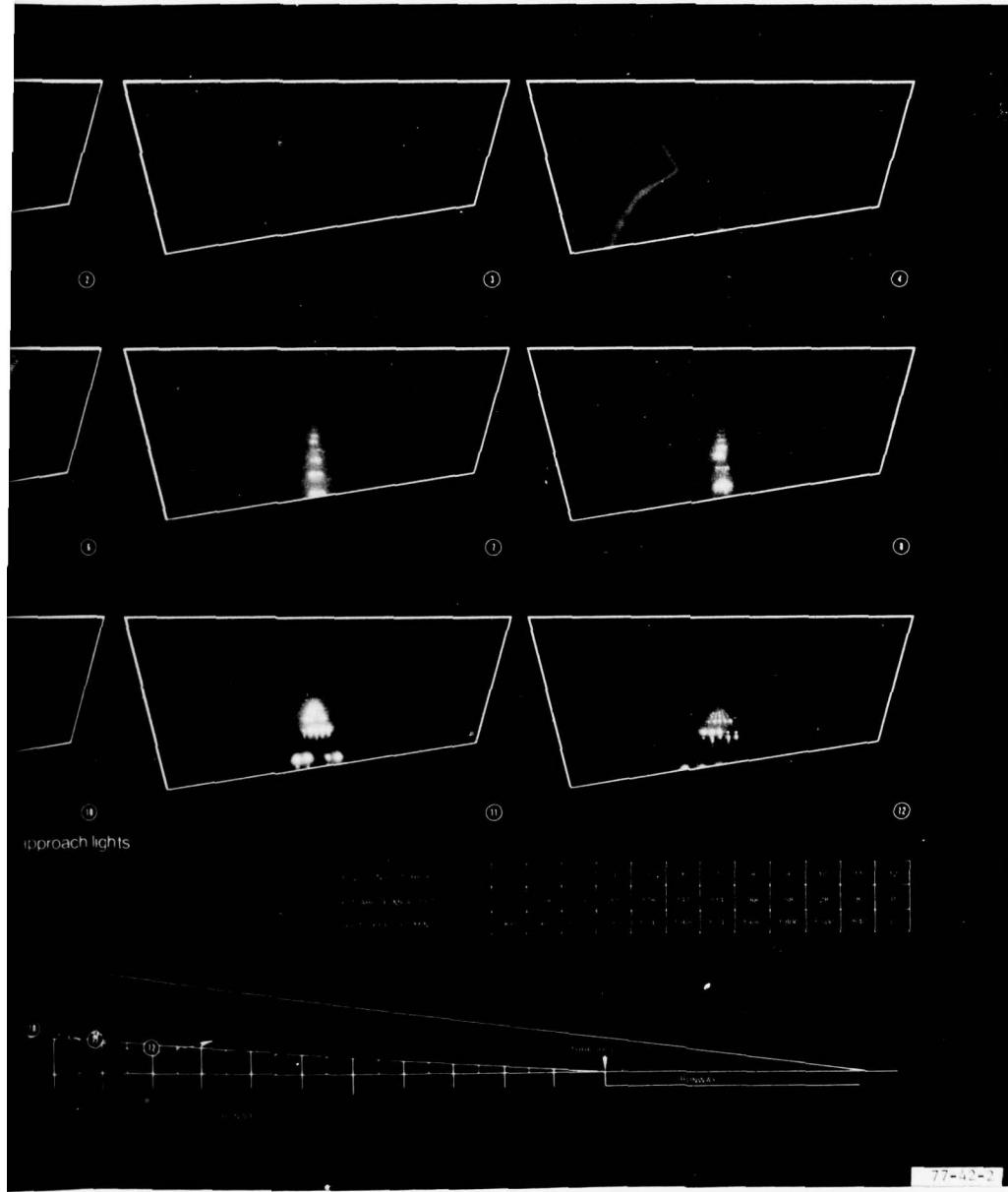


FIGURE 3. SIMULATED NIGHT LANDING INCIDENT DUE TO APPROACH LIGHT ILLUSION (REPRINTED W



APPROACH LIGHT ILLUSION (REPRINTED WITH PERMISSION FROM INDEX No. 291)

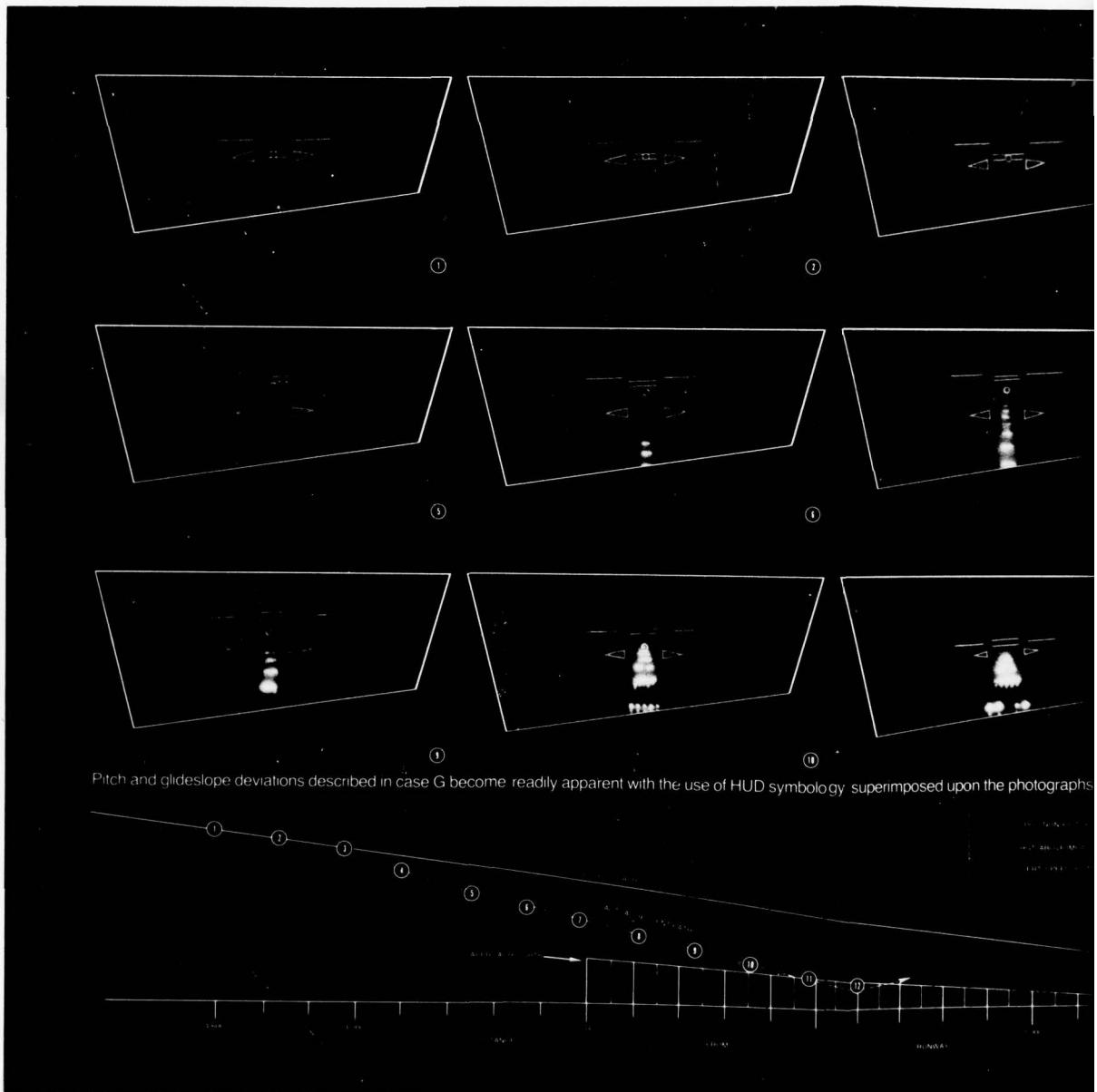
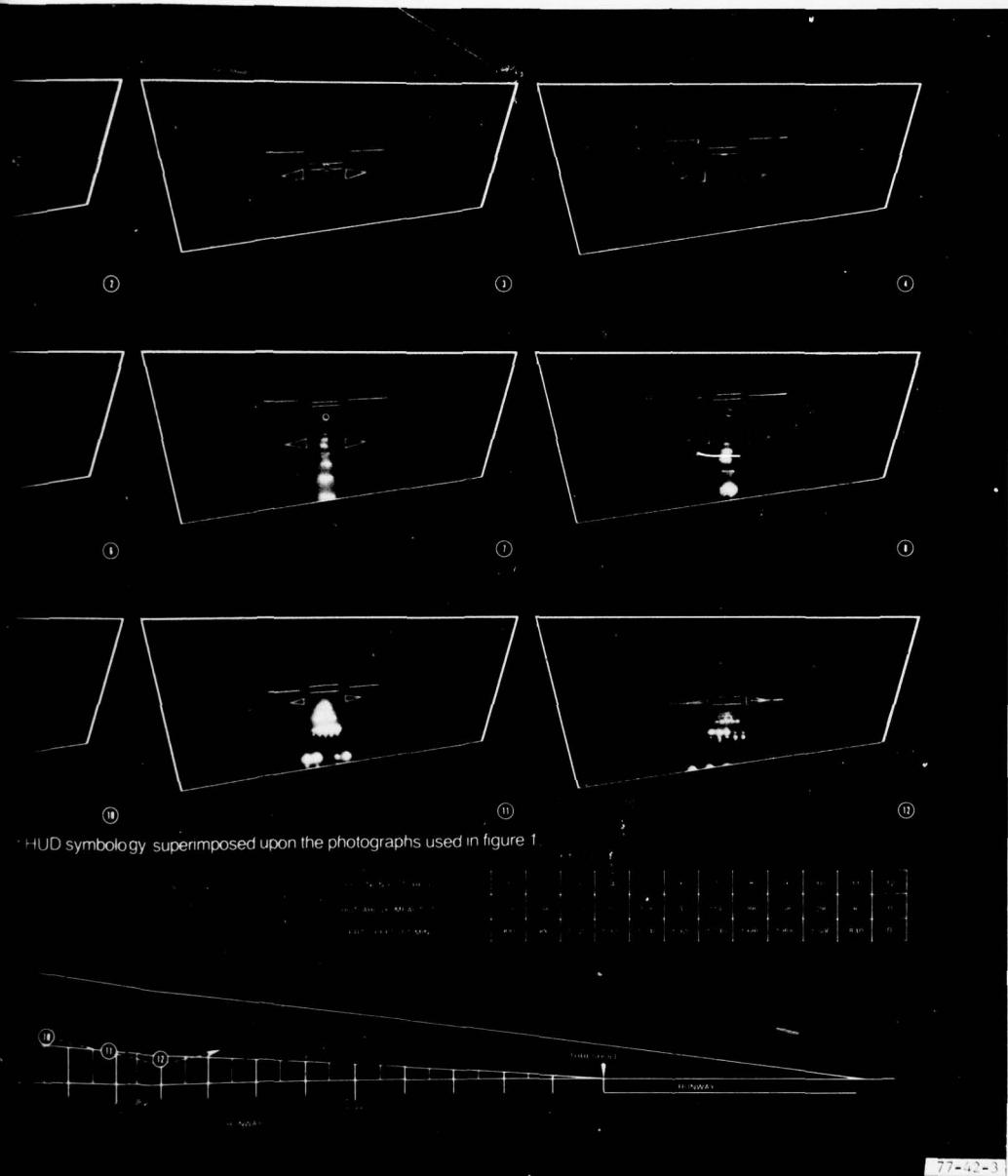


FIGURE 4. SIMULATED NIGHT LANDING INCIDENT WITH SUPERIMPOSED HUD SYMBOLS (REPRINTED)



HUD symbology superimposed upon the photographs used in figure 1.

SUPERIMPOSED HUD SYMBOLS (REPRINTED WITH PERMISSION FROM INDEX NO. 291)

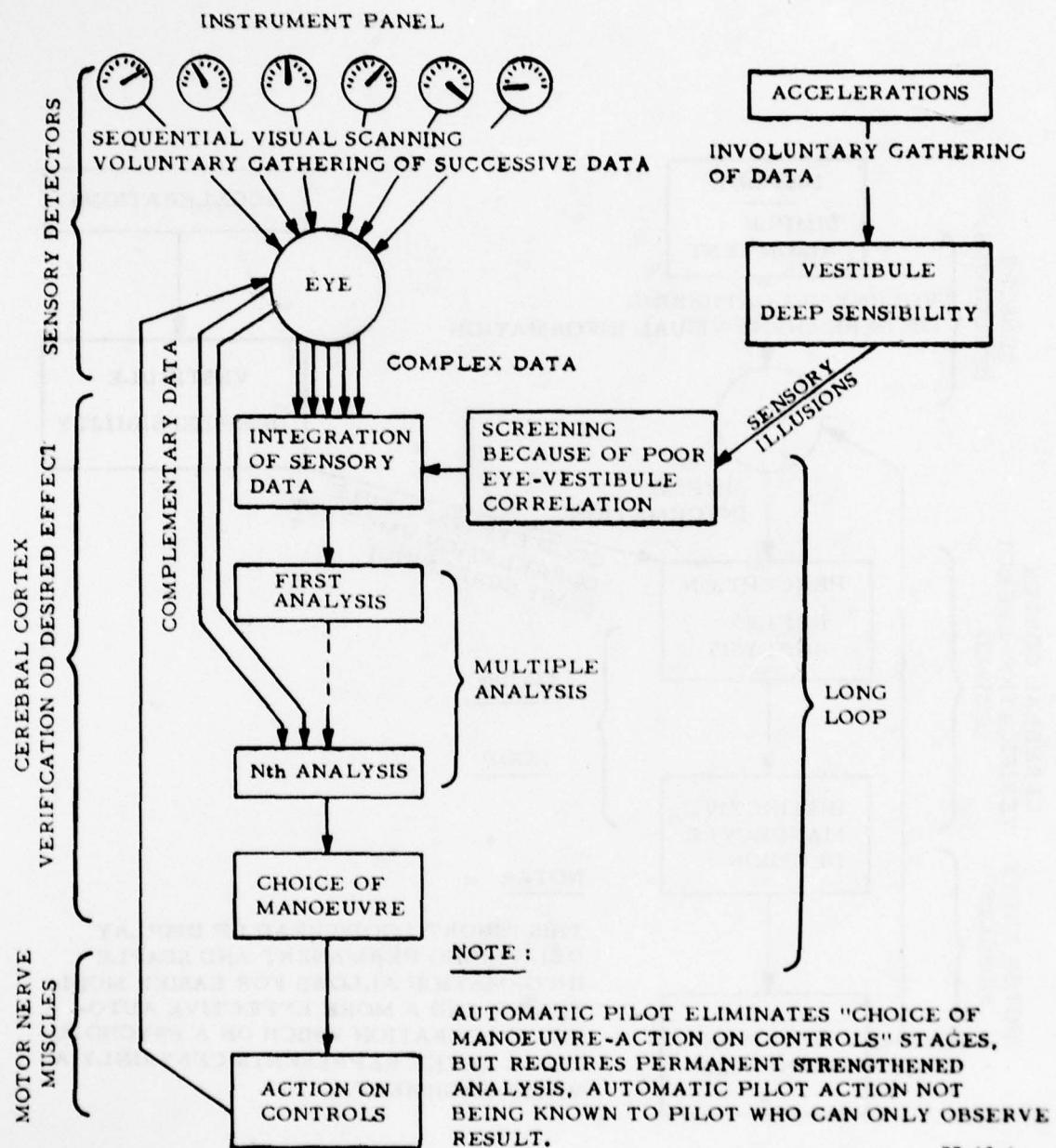


FIGURE 5. VISUAL PROCESSING USING A STANDARD FLIGHT PANED (STD HUD)
(REPRINTED WITH PERMISSION FROM INDEX No. 176)

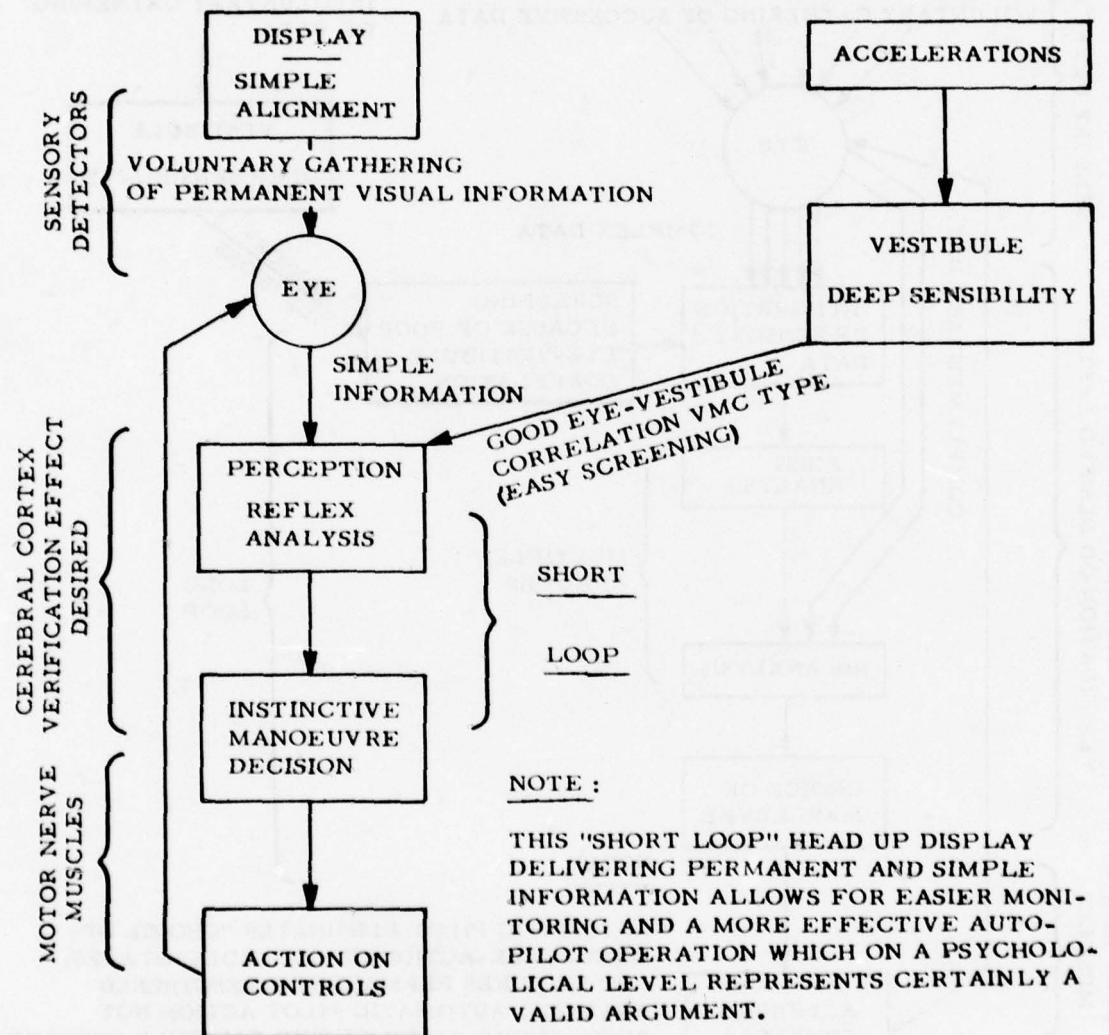


FIGURE 6. VISUAL PROCESSING USING A HUD (REPRINTED WITH PERMISSION FROM INDEX No. 198)

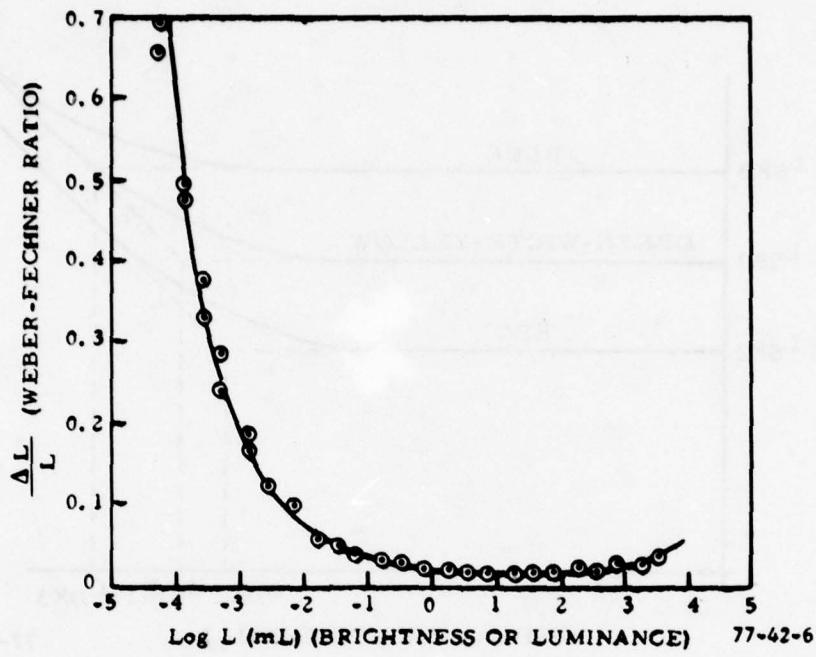


FIGURE 7. THE RELATIONSHIP BETWEEN VISUAL ACUITY AND ILLUMINATION DETECTABILITY (DAYLIGHT)

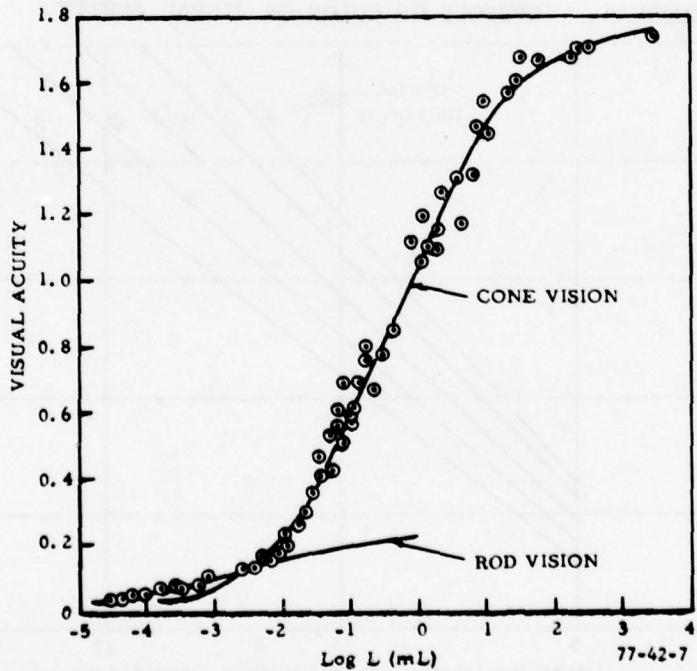
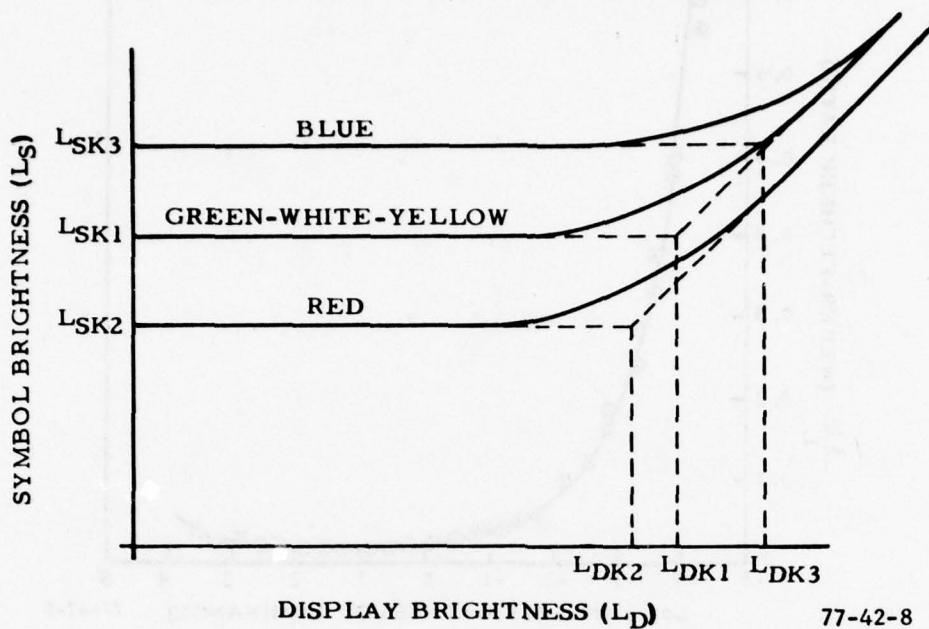
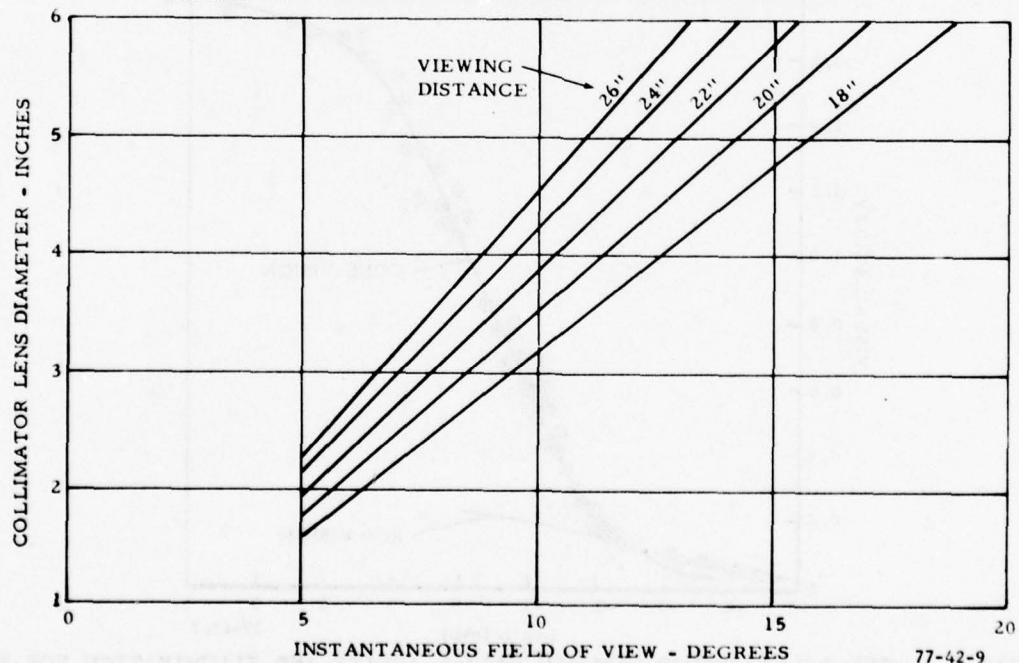


FIGURE 8. THE RELATIONSHIP BETWEEN VISUAL ACUITY AND ILLUMINATION FOR ROD AND CONE VISION (REPRINTED WITH PERMISSION FROM INDEX No. 108)



77-42-8

FIGURE 9. EFFECTS OF COLOR ON VISUAL ACUITY



77-42-9

FIGURE 10. INSTANTANEOUS FIELD OF VIEW AS A FUNCTION OF VIEWING DISTANCE AND COLLIMATOR LENS DIAMETER--REFRACTIVE OPTICS SYSTEM

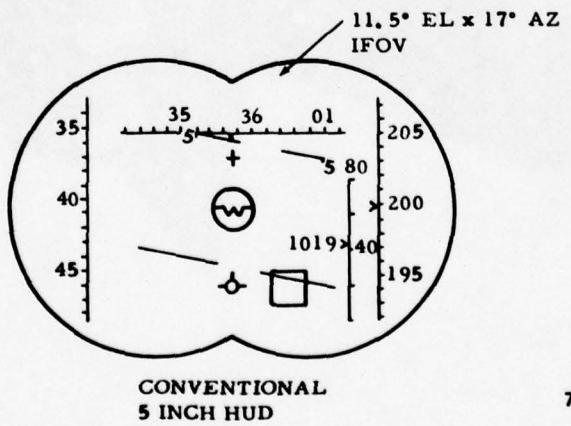
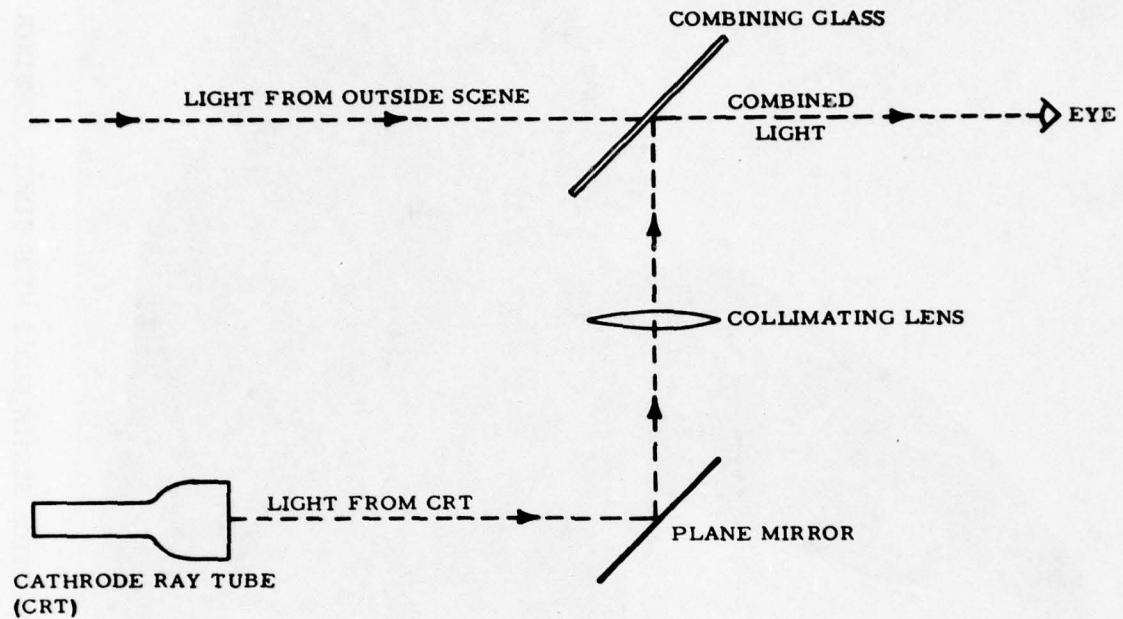
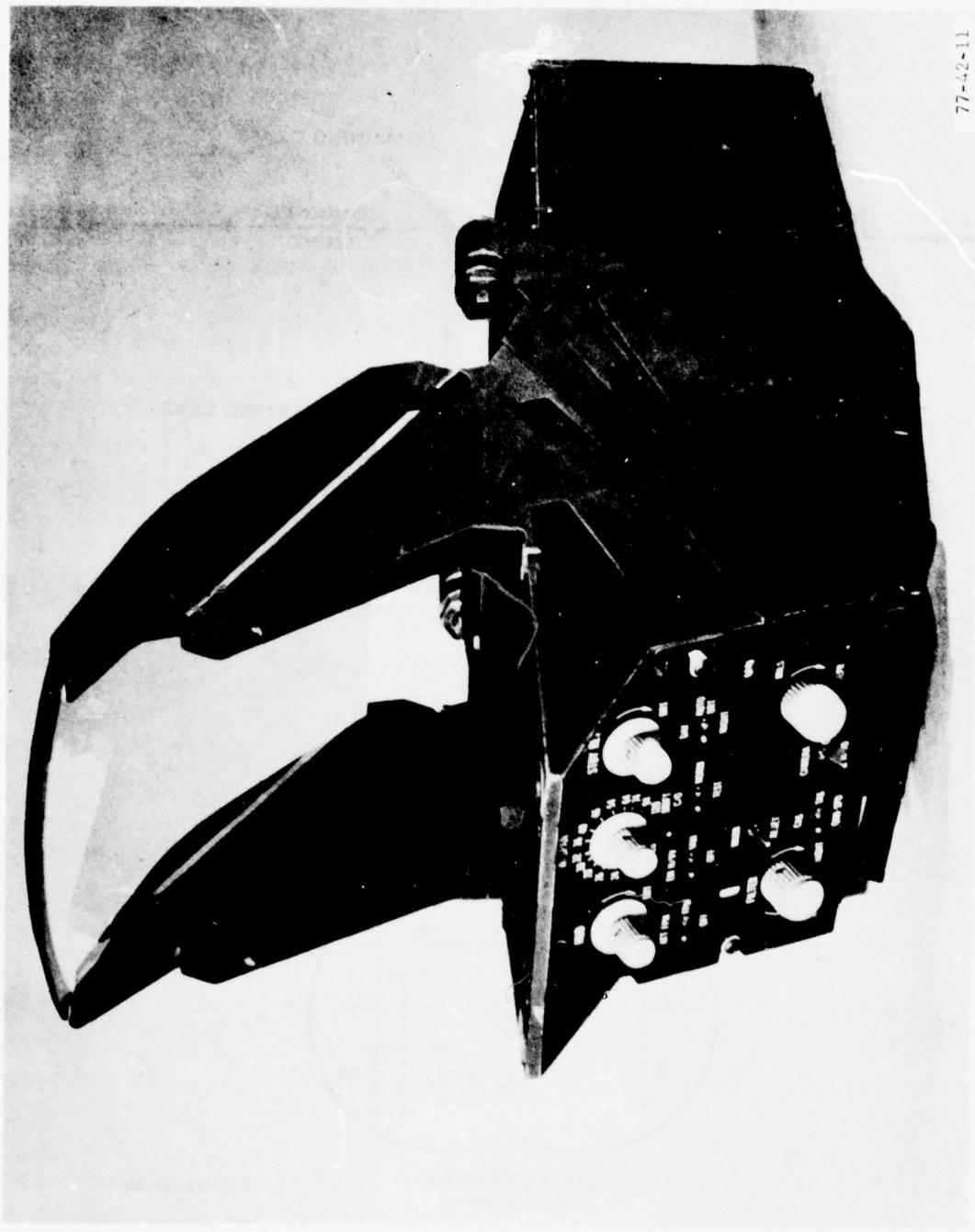


FIGURE 11. OPTICAL PATH FOR A CONVENTIONAL REFRACTIVE OPTICS HUD

77-42-11

FIGURE 12. CONVENTIONAL REFRACTION OPTICS SYSTEM HUD'S WITH SINGLE COMBINER LENS



77-42-12

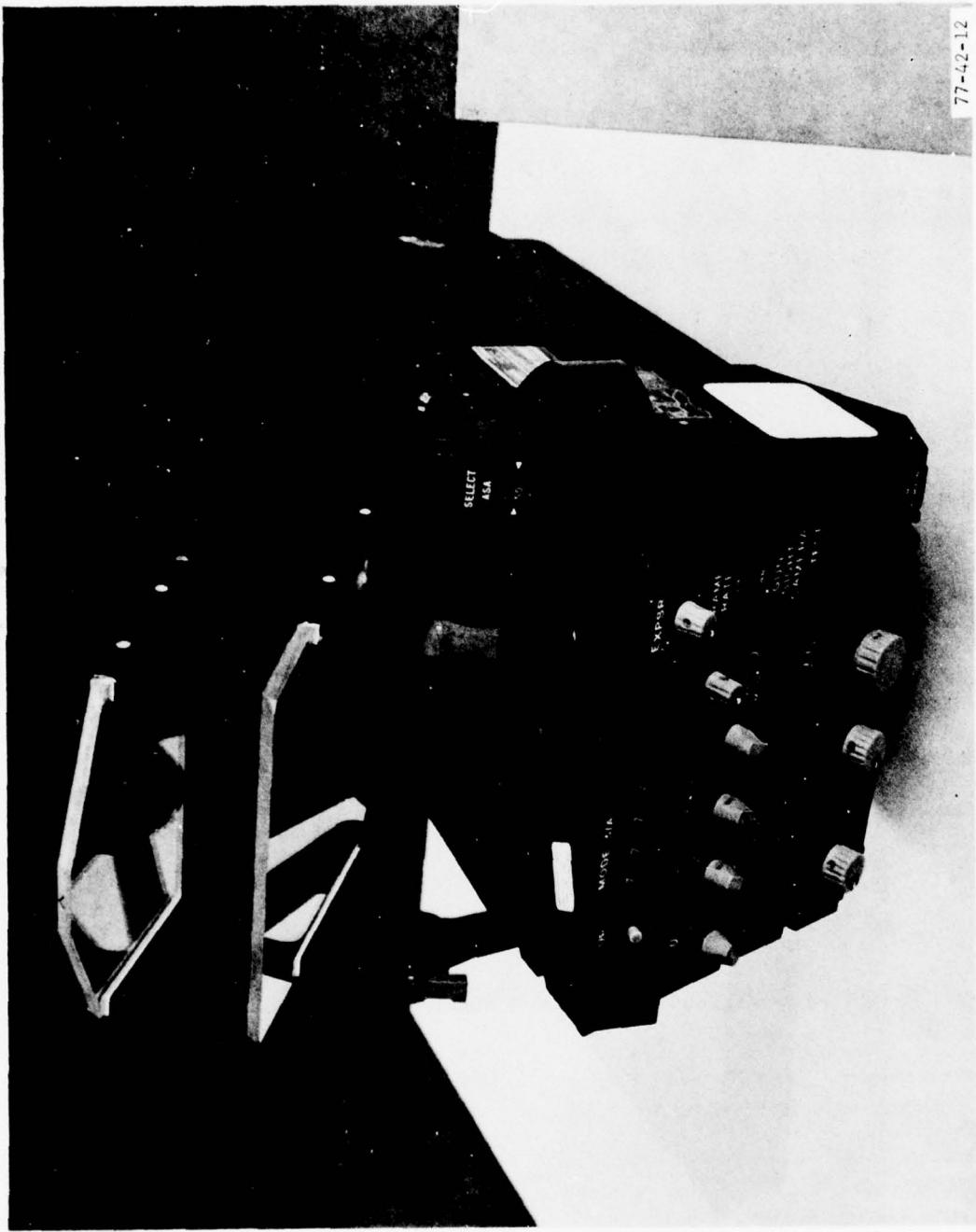
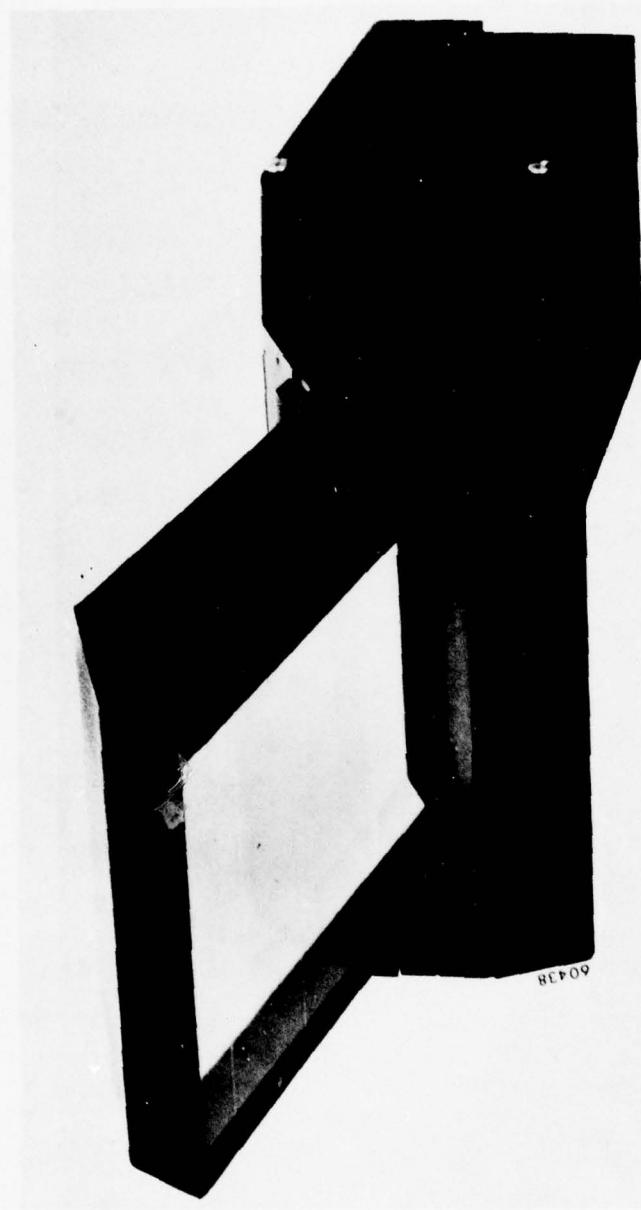


FIGURE 13. CONVENTIONAL REFRACTION OPTICS SYSTEM HUD'S WITH DUAL COMBINER LENS



77-42-21

FIGURE 14. MULTICOMBINER HUD

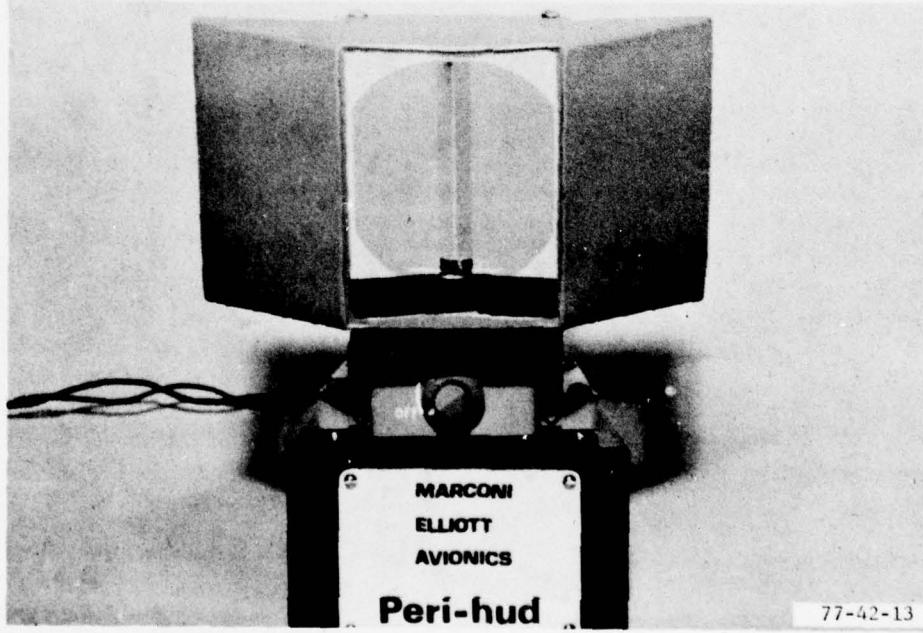
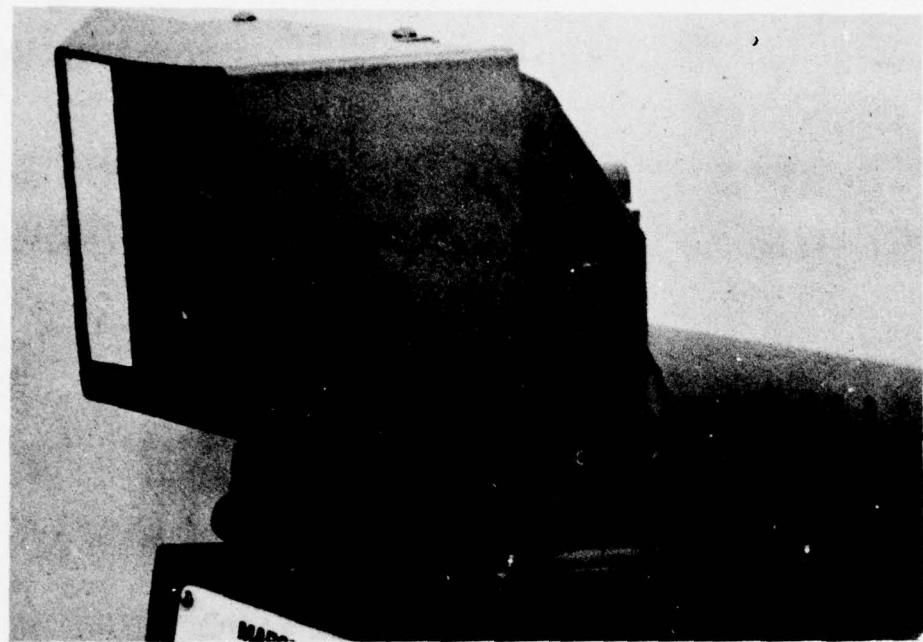


FIGURE 15. PERI-HUD (REPRINTED WITH PERMISSION FROM MARCONI-ELLIOTT AVIONICS)

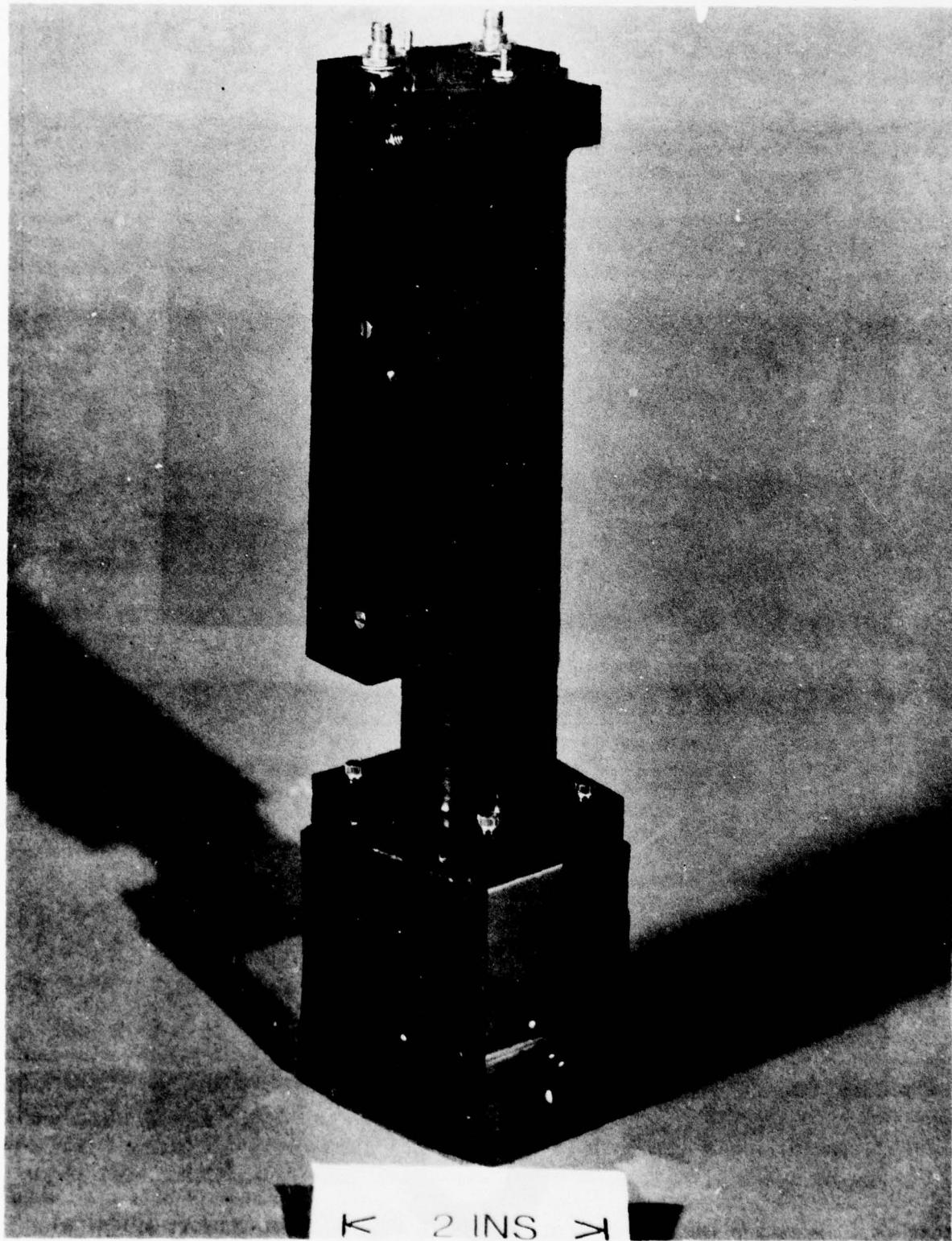


FIGURE 16. MONO-HUD (REPRINTED WITH PERMISSION FROM MARCONI-ELLIOTT AVIONICS)

FIGURE 3. SIMULATED NIGHT LANDING INCIDENT DUE TO APPROACH LIGHT ILLUSION (REPRINTED W

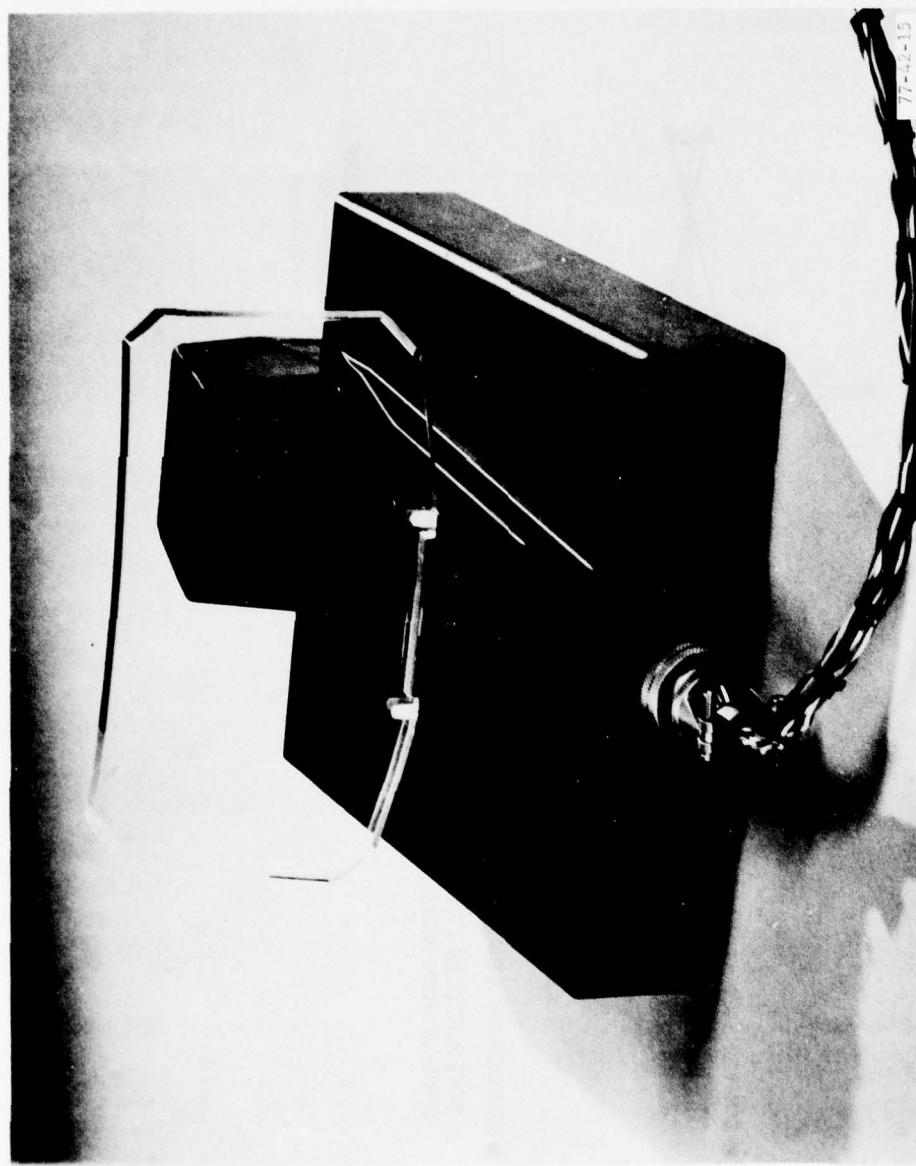


FIGURE 17. MICRO-HUD (REPRINTED WITH PERMISSION FROM BENDIX FLIGHT SYSTEMS DIVISION)

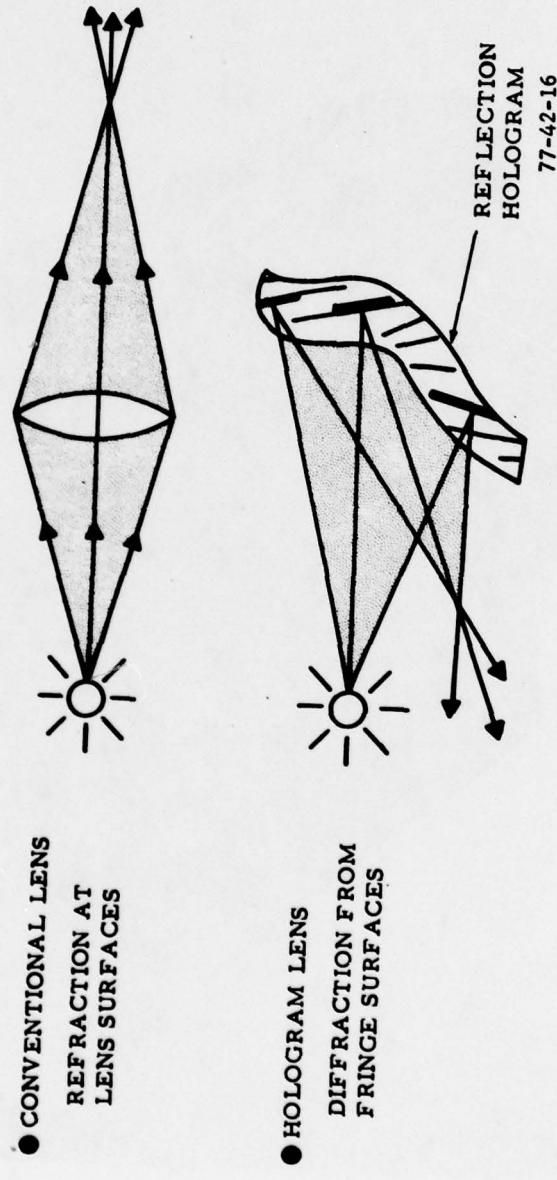


FIGURE 18. DIFFRACTION OPTICS VERSUS REFRACTION OPTICS

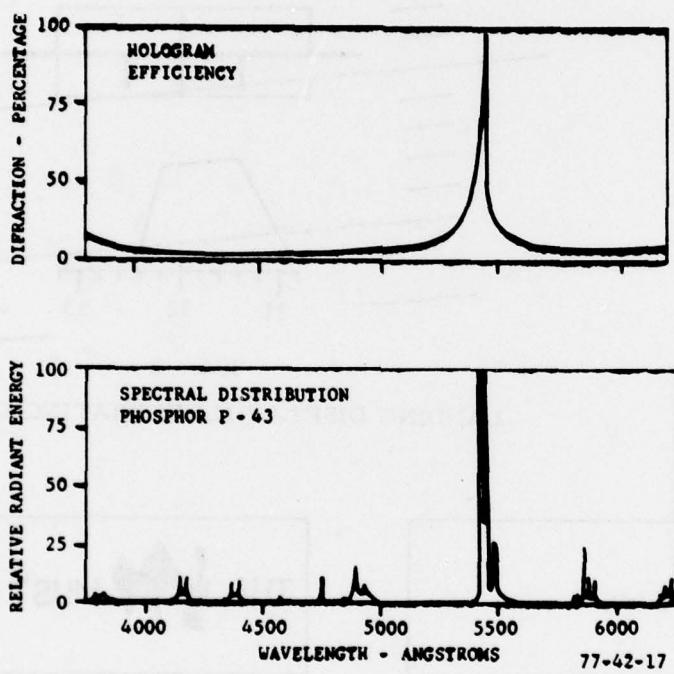
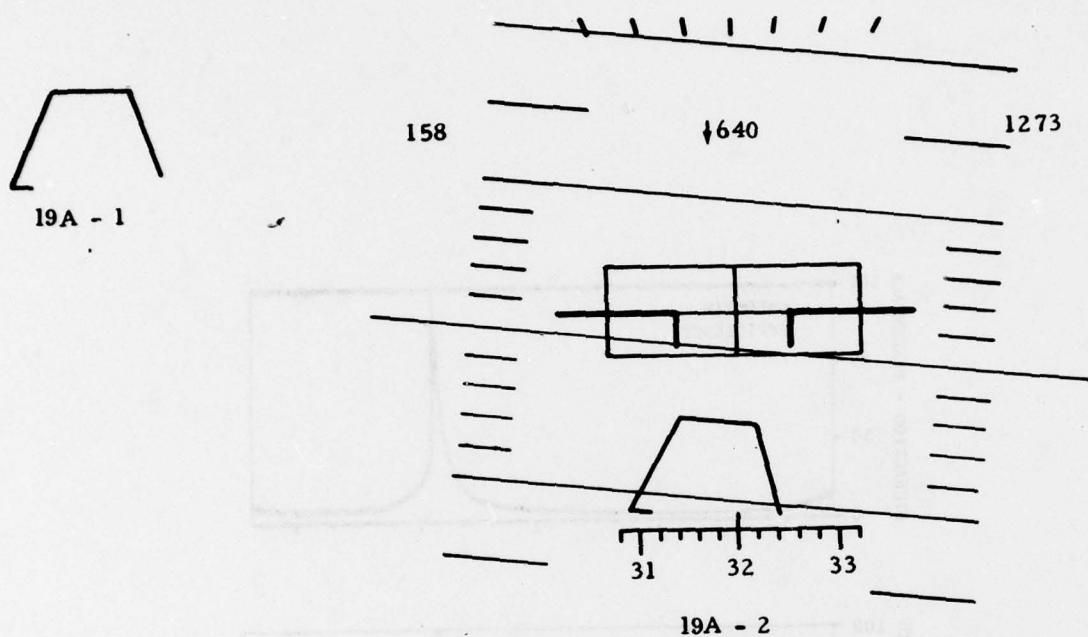
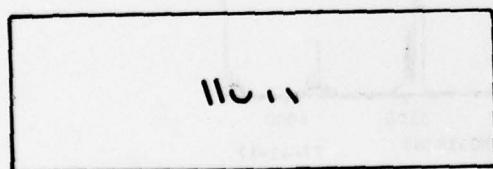


FIGURE 19. DIFFRACTION OPTICS EFFICIENCY



LANDING DISPLAY ILLUSTRATING CONTEXT



19B - 1
EXAMPLE OF PARTIAL INFORMATION
OUT OF CONTEXT



19B - 2
EXAMPLE OF PARTIAL INFORMATION
IN CONTEXT.

77-42-18

FIGURE 20. DISPLAY SYMBOLS ILLUSTRATING CONTEXT (REPRINTED WITH PERMISSION
FROM INDEX No. 272)

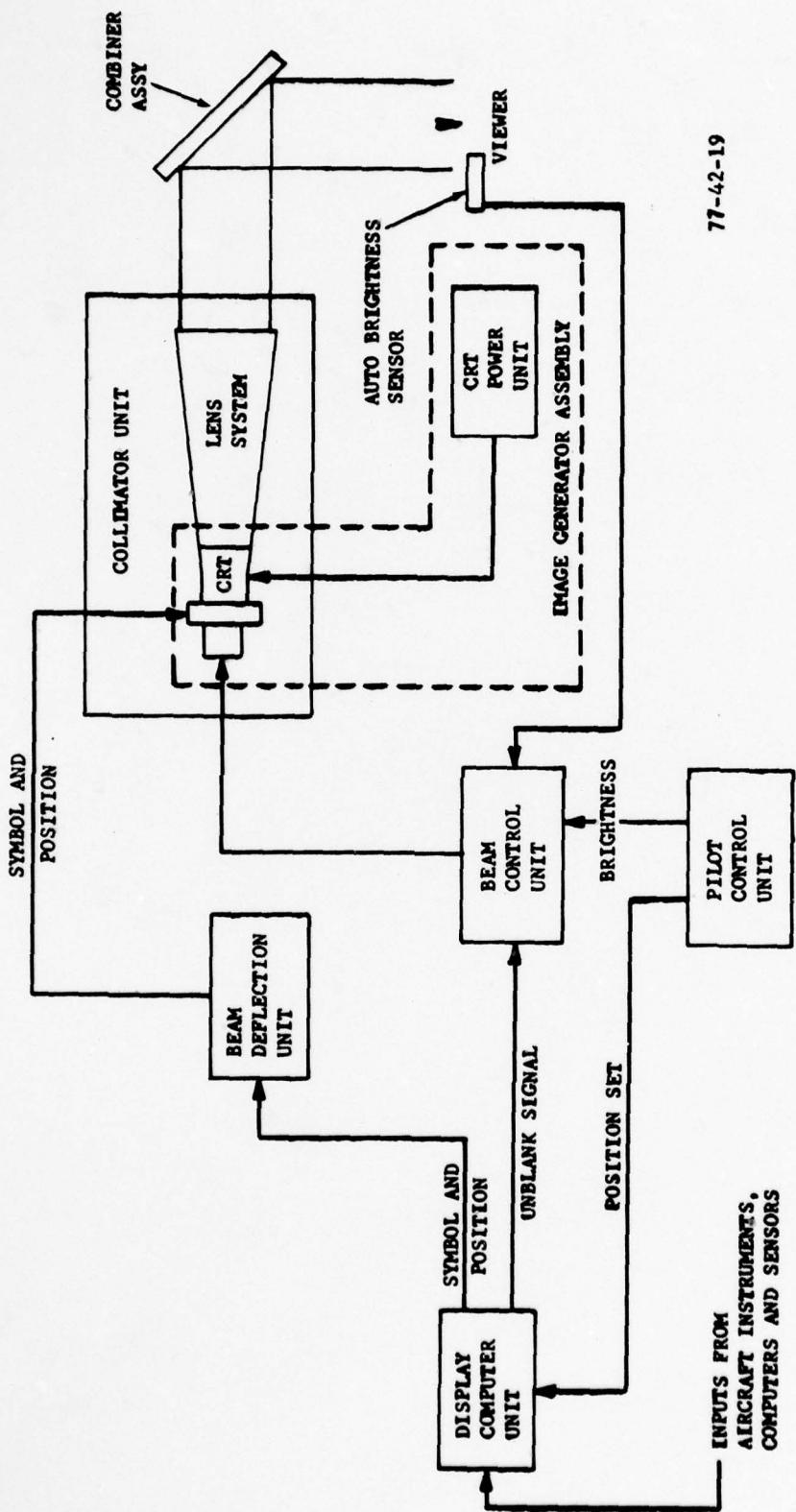


FIGURE 21. HUD BLOCK DIAGRAM (REPRINTED WITH PERMISSION FROM INDEX NO. 141)

APPENDIX A

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Schweizer, G., AGARD 55, 1970

40. CONTROL--DISPLAY PILOT FACTORS PROGRAM

Anonymous, USAF Instrument Pilot Instructor School, Air Force Flight Dynamics Lab., IPIS-63-1, December 1963

41. CONTROL INFORMATION IN VISUAL FLIGHT

Naish, J. M., In NASA, Washington 7th Ann. Conf. on Manual Control, Douglas Aircraft Co., Inc., Santa Monica, Calif., (N73-10104 01-05) 1972
The purpose of the inquiry is to determine how precisely a pilot can estimate the movements of his vehicle, and thus exercise control, during an unaided visual approach. The method is to relate changes in the forward view, due to movements along and across the approach path, to human visual thresholds and errors. The results throw some doubt on human visual thresholds and errors. The results throw some doubt on the usefulness of a runway symbol as a source of displayed information.

42. CONTROL TECHNIQUE AND FLIGHT QUALITY OF NEW GENERATION AIRCRAFT

Wanner, J. C. L., Journee Louis Bleriot, 24th, London, England, No. 31, April 22, 1971

Investigations have shown the necessity of reducing crew workloads in order to improve flight safety of military and civil aircraft. This paper explains the study which led to a definition of the various components of a modern cockpit.

43. CRITERIA FOR APPROVAL OF CAT IIIa LANDING WEATHER MINIMA
FAA Advisory Circular, AC 120-288, December 1, 1977

44. CRITERIA FOR APPROVING CAT I AND CAT II LANDING MINIMA FOR FAR 121 OPERATORS
Anonymous, FAA Advisory Circular, AC 120-129, December 15, 1971

45. DECISION HEIGHT, RUNWAY VISUAL RANGE AND THEIR RELATIONSHIP

Anonymous, ICAO AWOP Working Group B Meeting, Paris, France, December 1974

46. DESCRIPTION OF A LANDING SITE INDICATOR (LASI) FOR LIGHT AIRCRAFT OPERATION
Fuller, H. V. and Outlaw, B. K. E., Langley Research Center, Langley Station, W. Va., NASA-TM-X-72811, January 1976

47. DESIGN AND FABRICATION OF HOLOGRAM OPTICAL ELEMENTS

Colburn, W. S. and Chang, B. J., AFAL-TR-74-281, Environmental Research Institution of Michigan, 1975

This report presents the results and conclusions of a program to design and fabricate hologram optical elements for Air Force applications. The effects of materials properties on hologram performance were examined, both analytically and experimentally.

48. DESIGN DECISIONS FOR A HUD

Doucette, A. R., Spectrum, Vol. 13, August 1976

The engineering approach used to solve problems in the original F14 windshield/HUD combiner configuration is outlined.

49. DETERMINING THE UTILITY OF EXPANDED PITCH SCALE AND FLIGHTPATH ANGLE AS DISPLAY PARAMETER

Barnette, J. F. and Intano, G. P., Instrument Flight Center, AD-A031, IFC-TR-76-4, October 1976

Ten subject pilots from the Instrument Flight Center conducted a pilot factors evaluation to determine the utility of expanded pitch scale and flightpath angle as display parameters.

50. DEVELOPMENT OF AN ADVANCED DISPLAY FOR A WIDE FIELD NIGHT VISION SYSTEM

Attler, A. R., Shenker, M. and Parr, A., Farrand Optical Co., Inc., Rept. No. PTR-2115, June 1974

This paper covers design, development and test of a version of pupil-forming head-up display system. Explained is the design for installation in a UH1 Helicopter cockpit.

51. DEVELOPMENT OF A FLYABLE ACOUSTO-OPTIC LASER BEAM DEFLECTION SYSTEM FOR A HUD OF THE FUTURE

Aronson, H. and Stolzenberger, R., Somet Corp., Oakland, New Jersey, Rept. No. AD-776-653, November 1973

This report describes a laser display which is to be used in a head-up display of the future. The uniqueness of the display is that it uses acousto-optic components for the modulation and deflection of the laser beam. There are no moving parts, which increased the reliability and life expectancy of the equipment.

52. DEVELOPMENT OF A LIGHT-WEIGHT, WIDE-FIELD, PUPIL FORMING HUD SYSTEM

Attler, A. R., Nagler, A. and Baum, M., Farrand Optical Co., Inc., Valhalla, N. Y., PTR 2104, November 1971

This report covers the design, development, and test of a lighter weight and wider angle version of a pupil-forming head-up display system previously built. The fabricated model was designed for installation in an A6A-type airplane.

53. DIGITAL COMPUTERS FOR HEAD-UP DISPLAYS

Edmunds, P. J., Aviation Review, August 1976

The development, design, and operating principles of the digital computer based HUD system are described. The HUD, carrying out both aircraft navigation and weapon-aiming guidance, consists of a display unit, which projects symbolic control and guidance images into the pilot's forward view, and a processing system. The potential of the HUD digital computers is discussed, along with its advantages over the analog techniques.

54. DIGITAL FBW FLIGHT CONTROL AND RELATED DISPLAYS---FLY BY WIRE

Hooker, D. S. and Vetsch, G. J., SAE Paper 751041, National Aerospace Engineering and Manufacturing Meeting, Culver City, Calif., November 17-20, 1975

An exploratory definition study has been conducted for an advanced fighter digital flight control system. Study results show that a triplex flight control system provides the lowest weight, the best maintainability, and the lowest cost of the candidate configurations considered. Results also indicate that mission-oriented flight control laws integrated with compatible displays and controllers can provide enhanced mission effectiveness and reduced pilot workload.

55. DISPLAY AND SYSTEM REQUIREMENTS FOR LOW-VISIBILITY FORMATION FLIGHT
Anderson, P. A. and Toivanen, M. L., JANAIR Rept. No. 71803, April 1972

56. DISPLAY EVALUATION FLIGHT TEST (DEFT)

Anonymous, General Electric Company, Utica, N. Y., DM-4404, September 1976
A technical proposal which was in response to an RRF from the Naval Air Development Center, Warminster, Pennsylvania, for a system design effort for (1) technology assessments (2) system configurations and detailed unit description of a programmable electro-optical cockpit display which will be available for use in future Navy aircraft.

57. A DISPLAY EVALUATION METHODOLOGY APPLIED TO VERTICAL SITUATION DISPLAYS
Baron, S. and Levision, W. H., in MIT Proc. of the 9th Ann. Conf. on Manual Control, NASA-CR-142295, 1973

An approach to display evaluation based on the optimal-control or state-variable model of the human operator is described. The foundations of the methodology are briefly described, and results are presented of its application to the analysis of vertical situation displays for STOL approach. This analysis includes the effects of both status and command displays on pilot workload and system performance.

58. A DISPLAY OF ENERGY-MANEUVERABILITY PERFORMANCE INFORMATION FOR FIGHTER AIRCRAFT

Loh, J. M. and Lusty, A. H. Jr., AIAA Paper 74-814, American Institute of Aeronautics and Astronautics, Mechanics and Control of Flight Conference, Anaheim, Calif., August 5-9, 1974

The need for a computer-generated HUD of energy-maneuverability performance information is established for the new generation of high-performance fighter aircraft. Display requirements are outlined, and a recommended display is discussed with respect to the relevancy of the parameters and the effectiveness of the formats. The utilization of the display is described relative to training and combat applications, and suggestions for further refinement and enhancement are outlined.

59. DISPLAY OF INFORMATION IN THE AIRCRAFT COCKPIT

Chappelow, J. W. and Rolfe, J. M., IEE Conference Publication No. 80, A71-70107 September 7-10, 1971

Explains developments and the improvements to cockpit instrument systems that have been made on airplanes since man began to fly. Explains an effective arrangement would provide aid so that at times of high demand, the pilot can delegate the routine information handling to the machine and remain free to exercise his skill and judgment in dealing with the unrehearsed and unexpected event. The HUD would be a great example of what can be done. This paper explains the pilot information it provides.

60. DISPLAYS

Brady, F. B., Avionics Navigation Systems (A69-34834 18-21) TL-695, This paper discusses the underlying principles of display system and describes display techniques. Systems representing various types that have gained some degree of acceptance are described.

61. DISPLAY SYSTEMS--AN AIRBORNE LOOK AHEAD

Braid, Optical Spectra, Vol. 8, February 1974

Description of the types of airborne optical display systems designed for use on modern military aircraft. Details are given on a HUD, a head-down display, and a helmet-mounted display.

62. DISPLAY TECHNOLOGY: AN ANNOTATED BIBLIOGRAPHY

White, R. T., Douglas Aircraft Co., Rept. No. MDC J5794, Line Item No. DAC-26-72-R217, December 1973

This report reviews the recent literature on computer-driven information display techniques that have potential applications to military and commercial aircraft. Major display techniques reviewed include CRT, electro-luminescent displays, light-emitting diodes, and liquid crystal displays.

63. DYNAMIC READING OF ANALOG AND DIGITAL DISPLAYS: A COMPARATIVE STUDY

Schubert, E., in MIT Proc. of the 9th Annual Conf. on Manual Control, 1975
Analog and digital meters are used to present the actual value of a parameter to an observer. The selection of a suitable display format for a special task depends essentially on whether accurate or quick reading is demanded. To combine both properties analog and digital elements have to be presented simultaneously in a way that is most suitable for human perception. Since this problem can not be solved by theoretical means, several display formats were compared by a comparative experimental study.

64. EFFECT OF COLOR ON PILOT PERFORMANCE AND TRANSFER FUNCTION USING A FULL-SPECTRUM, CALLIGRAPHIC, COLOR DISPLAY SYSTEM

Chase, W. D., Ames Research Center, NASA, AIAA Conference, Dayton, Ohio, April 1976

A study has been conducted with the full-spectrum, calligraphic, computer-generated display system to determine the effect of chromatic content of the visual display upon pilot performance during the landing approach maneuver. This study presents the results of an experiment designed to determine the effects of display color content by the measurement of both vertical approach performance and pilot describing functions. This method was selected to more fully explore the effects of visual color cues used by the pilot. Two types of visual color cues used by the pilot. Two types of landing approaches were made; dynamic and frozen range with either a landing approach scene or a perspective array display. The landing approach scene was presented with either red runway lights and blue taxiway lights or with the colors reversed, and the perspective array with red lights, blue lights, or red and blue lights combined. The vertical performance measures obtained in this experiment indicated that the pilots performed best with the blue and red/blue displays, and worse with the red displays.

65. THE EFFECT OF DAZZLE ON ELECTRONIC DISPLAY VISIBILITY IN MODERN HIGH-PERFORMANCE AIRCRAFT COCKPITS

Jainski, P., Royal Aircraft Establishment, Farnborough, England, RAE-LIB TRANS-1545, March 1971

This summarizes the report of a series of observations made by the author over a period ending in 1969. Formulae describe the main data.

66. EFFECTS OF DISPLAY FORMAT ON PILOT DESCRIBING FUNCTION AND REMNANT
Jex, H. R., Allen, W. and Magdeleno, R. E., 7th Annual Conference on Manual Control, University of Southern Calif., NASA SP-281, June 2-4, 1971
As part of a program to develop a comprehensive theory of manual control displays, six display formats were used by three instrument-rated pilots to regulate against random disturbances with a controlled element. All were scaled to equivalent movement and apparent brightness. Measures included overall performance, describing functions, error remnant power spectra, "critical instability" scores, and subjective display ratings. Simple analytical models are presented which show good agreement with the preliminary test data, and a tentative set of rules for estimating format effects of the display/pilot/vehicle system are given.

67. EFFECTS OF VISUAL FLIGHT DISPLAY DYNAMICS ON ALTITUDE TRACKING PERFORMANCE IN A FLIGHT SIMULATOR

Weener, E. F., Howe, R. M. and Pew, R. W., In MIT Proc. of the 9th Annual Conference on Manual Control, 1975
A study of the effects of visual display dynamics on pilot tracking performance in a simulator has been performed. The tracking task consisted of maintaining the piloted aircraft at the same altitude as two aircraft positioned 300 feet ahead, as would be required in level formation flying. Experiments were run using two experienced pilots and two substantially different longitudinal dynamics for the piloted aircraft.

68. ELECTRONIC AIRBORNE DISPLAYS

Bennett, M. R., AGARD-CP-167, December 1975
Problems of airborne displays were considered. Reports in the following areas were presented: trends in the field of airborne displays, evaluation and assessment procedures for airborne display systems, display devices and materials, data processing, and displays for particular applications.

69. ELECTRONIC AIRCRAFT DISPLAYS

Beyer, R., Rept. No. DLR-FB-72-43, 1972
A survey of electronic cockpit displays is presented with particular emphasis on display requirements, technology, implementation, system integration, and assessment. The concepts of head-up, head-down and eyeglass displays are discussed in relation to human factors engineering. The quality assessment is discussed based on instrument and pilot measurements.

70. ELECTRONICALLY OR OPTICALLY GENERATED DISPLAYS FOR AIRCRAFT CONTROL AND COMBAT CUE INFORMATION

Anonymous, Department of Defense, Military Standard MIL-STD-884C, 25 April 1975

71. ELECTRONIC AND OPTICALLY GENERATED AIRCRAFT DISPLAYS: A STUDY OF STANDARDIZATION REQUIREMENTS

Anonymous, The Matrix Corporation, No. NR 213-060, May 1968
This study reviewed and analyzed the research literature relating to electronically and optically generated aircraft displays. The purpose was to provide background information to support standardization of such displays for military aircraft. The results have been set forth under three major headings: (1) information requirements, (2) symbology, and (3) display characteristics.

72. THE ELECTRONIC DISPLAY OF PRIMARY FLIGHT DATA

Anonymous, AGARD-CP-55, RAE, Farnborough, England, March 1970

The stage has been reached where space for the additional interfaces with which the crewman has to cope can be found only by the utilization of hitherto unused areas or through the use of time-sharing of existing areas. This paper discusses examples of both these solutions and highlights some of the problems that may be encountered.

73. ELECTRONIC DISPLAYS OF FLIGHT INFORMATION

Sones, J., Electronics and Civil Aviation International Conference, Paris, France, Vol. 2, June 26-30, 1972

Electronic displays are very useful because they are presented in a manner in which they can be easily assimilated and provide the precise data required only at the time when the data are needed. The characteristics of the electronic HUD are discussed together with the symbols used for providing the information, the function of a typical head-down display, advances in colored displays, and the question of device installation.

74. ELECTRONIC HEAD-UP DISPLAY

Beranovsky, M., Zpravodaj Vzlu, No. 6, 1971

Advantages of HUD, providing indications of aircraft instrument data in a symbolic form at the pilot's eye level, are described. A basic block diagram of display is presented with a short description of the function of the individual units involved. A review is given of instrument data and the symbolism as used in instruments of this type.

75. ELECTRO-OPTICAL TECHNOLOGY ASSESSMENT

Compton, R. D., Electro-Optical Systems Design, Vol. 6, September 1974

The present work gives a general description of some current information display techniques, indicating which ones have proven most successful and apt to survive. Main types of display systems considered are large-screen light-valve systems, airborne cockpit displays, liquid crystal displays, and HUD. A typical EIDAPHOR system and HUD systems are diagrammed.

76. EVALUATION OF AIRBORNE AUDIO-VIDEO RECORDINGS AS A TOOL FOR TRAINING IN THE A-7D TACTICAL FIGHTER

Fitzgerald, J. A. and Moulton, D. L., Air Force Human Resources Lab., Williams AFB, Ariz., AFHRL-FT-TR-72-55, AD-744/041, October 1970

The report documents the results of a study to evaluate an airborne audio video recording system in a HUD-equipped aircraft. It recommends that such a capability be a basic design consideration in all new fighter aircraft.

77. EVALUATION OF AN AIRBORNE AUDIO-VIDEO RECORDING SYSTEM FOR AIRCRAFT EQUIPPED WITH HUD

Fitzgerald, J. A., Air Force Human Resources Lab., Williams AFB, Ariz., Flying Training Division, AD-73618, AFHRL-TR-71-20, May 1971

The objective of the project was to provide a low-cost reliable audio-video recording system (AVRS) for aircraft equipped with HUD that would be capable of recording both the external real world cues through the aircraft's forward windscreen as well as the symbology of the HUD projected on the aircraft's combining glass. The ultimate objective is a research program to assess audio-video recording in HUD-equipped aircraft as both technique for improvement of training and as a tool for pilot proficiency assessment.

78. EVALUATION OF A WIDE ANGLE HEAD-UP DISPLAY OPTICAL SYSTEM

Hussey, C. L., Naval Air Development Center, Warminster, Pa., Rept. No. NADC-AM-7042, AD-878-022, December 1970

This report covers the evaluation of an experimental wide-angle optics projection system for an advanced aircraft HUD. Optical distortions of transmitted and reflected light were measured. Light distortion measurements, conclusion, and recommendations are included in the report.

79. EVALUATION OF EXTERNALLY MOUNTED HEAD-UP DISPLAY (PCI)

Taylor, R. K. and McTee, A. C., Instrument Pilot Instructor School, Randolph AFB, Tex., Rept. No. IPIS-TR-71-2, AD-888-371, August 1971

Three instrument-rated instructor pilots flew 96 approaches in a T-39 aircraft in evaluating the concept of an electromechanical HUD, mounted forward of the aircraft windscreens. All displayed parameters were judged by the subjects to be desirable for display on a HUD. This report explains some of the problems that were encountered.

80. EVALUATION OF HOLOGRAM OPTICAL ELEMENTS

Latta, J. N., Willow-Run Lab, Rept. No. 197400-1-F, August 1973

81. EVALUATION OF HOLOGRAPHIC ELEMENTS IN A HUD

Latta, J. N. and Champagne, E. B., Michigan Univ. Ann Arbor Inst. of Science and Technology, Rept. No. 11057-3-F, AD-758 057, March 1973

This report examines work on the application of a hologram optical element to a pilot's HUD. Two problem areas are addressed: the compensation of a wavelength shift in the hologram geometry from construction to reconstruction, and compensation of the effects of dispersion on the image in a hologram element system as a result of the spectral bandwidth of the illumination source.

82. EVALUATION OF THE SONY HUD TV MONITOR SYSTEM IN THE YA-7H AIRPLANE

Anonymous, Naval Air Test Center, Patuxent, Maryland, NATC-SA-24R-75, AD-B005 506L

A one flight evaluation was conducted with a Sony HUD TV monitor system in the YA-7H to evaluate the ability of the Sony HUD TV monitor system to provide the instructor pilot information relative to the student's pilot's employment of the HUD.

83. EVALUATION OF THE THOMPSON-CSF CV-91 AND OBSERVATION OF THE TC-121 HEAD-UP DISPLAYS

Reising, J. M. and Augustine, W. L., AF Flight Dynamics Lab, Wright-Paterson AFB, Ohio, Rept. No. AFFDL-TM-72-9, October 1972

The TC-121 and the CV-91 was demonstrated in a Nord 262 aircraft at Wright-Paterson AFB, Ohio. This report will explain the results.

84. AN EVOLUTIONARY APPROACH TO THE DESIGN OF FLIGHT DECKS FOR FUTURE CIVIL TRANSPORT AIRCRAFT

Bateman, L. F., British Corp.

A paper presented to THE GUILD OF AIR PILOTS AND AIR NAVIGATORS on September 9, 1976

85. THE EVOLUTION OF ELECTRONIC DISPLAYS FOR CIVIL AND MILITARY AIRCRAFT

McKinlay, W. H., Interavia, Vol. 29, February 1974

The HUD is established in most advanced military aircraft, but has not found a place in civil aircraft for a variety of reasons, including the increased emphasis on automatic flight control. The state-of-the-art of electronic displays in aircraft is considered, giving attention to the overall system configuration, the interfaces, and the data transmissions.

86. THE EVOLUTION OF HEAD-UP DISPLAYS

Smith, J. H., Interavia, Vol. 27, August 1972

Electronic HUD systems for military applications have now been under development in the United Kingdom for about 16 years. HUD systems are not specified as an essential part of the avionics system of virtually all modern strike aircraft. The prime justification for the installation of a HUD system is to enable the best possible accuracy and flexibility of weapon delivery to be obtained. The system components of the HUD are described.

87. EVOLUTION OF THE ELECTRONIC HEAD-UP DISPLAY

Smith, J. H., Aviation Review, AGARD CP-96, Paper 74, September 1972

The electronic HUD is the result of a number of evolutionary steps from the lead-computing electromechanical reflector sight. The HUD is based on the versatility and adaptability of the CRT and the electronic computer. Modern HUD systems have a digital system of symbol generation to give system flexibility, high reliability over a wide temperature range, inherent redundancy, and low weight and minimum volume. The presentation can be updated by changing the symbology, which is usually accomplished by the exchange of one or more plug-in modules.

88. EXPERIMENTAL TESTING OF FLIGHT-CONTROL HUD

Berjal, M., Electronics and Civil Aviation, International Conference, Vol. 2, Paris, France, June 26-30, 1972

Discussion of the results of a series of flight tests performed since 1965 upon five flight-control HUD system developed in France. The test purposes, system design, equipment installation particulars, and obtained results pertaining to each test series are reviewed, along with the merits of each system tested. Future research is pointed out.

89. AN EXPLORATORY SIMULATION STUDY OF A HUD FOR GENERAL AVIATION LIGHTPLANES

Harris, R. L., Sr. and Hewes, D. E., NASA Langley Research Center, Hampton, Va., Rept. No. NASA TN D-7456, December 1973

The concept of a simplified HUD referred to as a landing-site indicator (LASI) for use in lightplanes is discussed. Results of a fixed-base simulation study exploring the feasibility of the LASI concept are presented in terms of measurements of pilot performance, control-activity parameters, and subjective comments of four test subjects.

90. F-4E AUSTERE HEAD-UP DISPLAY

Lawler, C. and Collins, S., Texas Instruments, Inc., Rept. No. TI-41-862402-01, AD-B004619L, December 1974

An Austere HUD (AHUD) was designed, fabricated, and delivered to the Air Force for flight test evaluation. The AHUD is an optical and electronic device that

projects collimated symbology into the pilot's forward field-of-view and thereby enhances his weapon delivery capability. For the purpose of flight test evaluation, the AHUD system was designed and fabricated to be a one-for-one physical replacement with the existing F4E electromechanical gunsight.

91. F-15 AIRCRAFT HEAD-UP DISPLAY PROCUREMENT SPECIFICATIONS

Anonymous, McDonnell Douglas Corp., St. Louis, Missouri, PS-68-870004, 1973

92. F-18 AIRCRAFT HEAD-UP DISPLAY PROCUREMENT SPECIFICATION

Anonymous, McDonnell Douglas Corp., St. Louis, Missouri, PS-74-870073, 1974

93. F-14 AIRCRAFT HUD

Doucette, A. R., Proceedings of the National Aerospace and Electronics Conference, (NAECON 1975), June 10-12, 1975

The optical principles involved in implementing a HUD in a sophisticated fighter aircraft are reviewed, and the original F14 configuration is described which used a conventional combiner and a vertical display indicator.

94. F-14A PROGRAMMABLE DISPLAY GENERATOR HUD SYMBOLOGY

Anonymous, Grumman Aerospace Corp., Rept. No. A51-232-R-73-7, October 1973

95. THE FAIL-SAFE LANDING

DeCellles, J. L. and Burke, E. J., ALPA's 17th Air Safety Forum, July 1970

96. FLIGHT ASSESSMENT OF HEAD-UP DISPLAY AS A CLEAR WEATHER APPROACH AID

Harlow, R. A., Royal Aircraft Establishment, Farnborough, England, Rept. No. RAE-TR-71141, July 1971

Flight trials were conducted by BLEU at RAE Bedford to assess the value of a HUD as a clear-weather approach aid. The results showed that a display providing glidepath displacement information-only produced a significant improvement in pilot's pitch performance compared with conventional visual approaches.

97. FLIGHT-CONTROL HEAD-UP DISPLAY

Martin, M., Electronics and Civil Aviation, International Conference, Paris, France, Vol. 2, June 26-30, 1972

Discussion of the assessed advantages of a flight-control HUD providing information on the velocity vector, angle of attack, potential slope, and real or synthetic ground reference data. Two types of equipment are discussed.

98. FLIGHT EVALUATION OF A HEAD-UP DISPLAY WITH REAL-WORLD OVERLAY FOR INSTRUMENT APPROACH AND LANDING OF V/STOL AIRCRAFT

Walchi, R. M., Halliday, W., Gold, T., and Rauch, K. N., Naval Air Test Center, Patuxent River, Md., Rept. No. NATC-SY-23R-75, AD-B008-208L, October 1975

A HUD concept with real-world overlay for V/STOL approach and landing was evaluated in a three-phase, tripartite, V/STOL instrumentation program. This report documents phase 2 of the three-phase flight test program.

99. FLIGHT EVALUATION OF A WIDE FIELD-OF-VIEW HEAD-UP DISPLAY INSTALLED IN

AN F-14 AIRCRAFT

Walchi, R. M. and Halliday, W. P., Naval Air Test Center, Rept. No. NATC-MST-134R-1, AD-B008-208L, August 1975

A Sperry wide field-of-view (WFOV) HUD system was installed, tested, and evaluated in an A6A airplane. A 25-flight test program was conducted. Ten design features which preclude WFOV HUD use as the primary flight and mission integrated display system for all-weather attack mission are discussed.

100. FLIGHT INFORMATION SCALE TEST FOR HEADS-UP AND PANEL MOUNTED DISPLAYS
DeBellis, W. B., Human Engineering Lab., Aberdeen Proving Ground, Md.,
Rept. No. HEL-TM-22-73, October 1973

Scales which were designed to provide altitude, airspeed, and heading information, were combined into six candidate flight display formats for heads-up and panel-mounted applications. Twelve U.S. Army Aviators flew each format under static base simulation conditions. Results of this experiment are indicated in this document.

101. FLIGHT TEST AND EVALUATION OF THE SPECTOCOM HEAD-UP DISPLAY INSTALLED IN AN A-5A AIRPLANE

Johnson, R. K. and Momiyama, T. S., Naval Air Test Center, Patuxent River, Md.,
Rept. No. NATC-FT-2222-65R-64, AD-867-878L, December 1969

Shore-based and shipboard flight test of the spectocom HUD were conducted to obtain human factors information on the HUD concept. The HUD concept in the carrier approach environment was determined valuable as an aid in reducing the probability of an accident-prone premature visual transition. A transition mode which provides all the instrument approach parameters and visual landing aid approach mode for use under conditions of reduced visibility are considered necessary for a carrier approach.

102. FLIGHT TESTS OF THE HEAD-UP DISPLAY IN DC-9-20 SHIP 382

Naish, J. M., Douglas Aircraft Co., MDC-LJ0878, September 1970

The investigation starts by discussing the symbol format of the HUD in terms of principles of selection, organization, and design, and their effect on performance. It then deals with optical and mechanical problems of installing an operational system in a commercial jet transport.

103. FLIGHT TESTS WITH A SIMPLE HUD USED AS A VISUAL APPROACH AID

Lamers, G. L., Advisory Group for Aerospace Research and Development, AGARD-CP-160, April 1974

104. A FLIGHT TRIALS ASSESSMENT OF THE USE OF ELECTRO-LUMINESCENCE AS A MEANS OF INTEGRAL LIGHTING OF A PILOT'S CONTROL UNIT

Shiel, R., RAE Tech Memo Avionics, February 16, 1969

105. FUNCTIONAL DESCRIPTION OF SYSTEM OPERATIONAL MODES FOR THE A-10A HEAD-UP DISPLAY

Suroda, T., Astronautics Corp. of America, FDM01581A, April 15, 1975

This document provides a functional description of system operational modes for the A10 HUD Subsystem (HUD 123), consisting of Astronautics Corp. of America (ACA) part number 150000 Projection Unit, 15100 Control Unit, and 152000 Electronic Symbol Generator.

106. FUTURE COCKPIT DISPLAYS

Wharf, J. H. and Ellis, B., Optics and Laser Technology, Vol. 7, February 1975
As aircraft systems become more complicated, it is necessary to display

information which was either not previously available or was provided by instruments which were unduly bulky, heavy, expensive, or unreliable. This paper considers possible display mechanisms for future cockpits and their performance in high ambient illumination. Results of subjective tests on light-emitting diode displays are discussed.

107. GUIDANCE AND CONTROL DISPLAYS

Anonymous, AGARD-CP-96, Paris, France, February 1971

108. HEAD COUPLED DISPLAY VISUAL DESIGN CONSIDERATIONS

Chisum, G. T., Naval Air Development Center, Rept. No. NADC-75013-40, March 1975
Several key areas of visual constraints which must be considered by designers of head-coupled displays are highlighted. Classical data related to the constraints are examined and the implications for the design constraints are evaluated.

109. HEADS UP!! . . . A LOOK AT THE F15 HUD

Plummer, C., Product Support Digest

Explains where the HUD came from and how we use it to navigate.

110. HEADS-UP DISPLAY SYSTEM USING NONPARAXIAL HOLOGRAPHIC LENSES

Oelfke, W. C., Naval Training Equipment Center, Orlando, Florida, NAVTRAEOUIPC-TN-38, AD-769 117, September 1973

A study was made of optical systems employing holographically-produced lens elements. The basic third-order aberration terms are defined for non-paraxial configurations of holographic lenses and three techniques of aberration balancing are suggested.

111. HEAD-UP AND OTHER DISPLAYS

Smith, J. H. and Chorley, R. A., Aircraft Engineering, Vol. 47, February 1975

The present work gives a description of a typical HUD installation, giving particular attention to the pilot's display unit, the EHT unit, the pilot's control panel, and the display waveform generator. The development of HUD systems is given a brief historical outline, and some future trends are indicated.

112. HEAD UP DISPLAY

Anonymous, The Society of Experimental Test Pilots, 1976

113. HEAD-UP DISPLAY

Anonymous, Sperry Flight Systems Division, Phoenix, Ariz., LJ-61-0019

Proprietary publication of Sperry Rand Corp.

114. HEAD-UP DISPLAY

Anonymous, Kaiser Aerospace and Electronics Corp., Palo Alto, Calif., March 1972

An overview outline of a HUD system for a medium fighter aircraft with an attack mission.

115. HEAD-UP DISPLAY

Anonymous, Newsletter/Information Exchange published by the ALPA All-Weather Flying Committee, July 1977

116. HEAD-UP DISPLAY

Lahr, H. R., Air Line Pilot's Association, Los Angeles, Calif., Contract Admin.
213-645-4055, December 10, 1976

117. HEAD-UP DISPLAY

O'Brien, J. E., Air Line Pilot's Association, Washington, D.C., November 1976

118. HEAD-UP DISPLAY

Foxworth, T. G., Huntingdon, N.Y., October 1, 1976

119. HEAD-UP DISPLAY

Anonymous, CATC Electronics News, Vol. 16, September 16, 1976

120. HEAD-UP DISPLAY

Horning, D. O., University of California, Berkley, Calif., FAA-RD-71-60,
May 1971

121. HEAD-UP DISPLAY--A PILOT'S EVALUATION

Therrien, R. L., Annual Corporate Aircraft Safety Seminar, 17th, Washington, D.C.,
April 17-18, 1972

The McDonnel Douglas HUD evaluated in a fan-jet falcon, was placed in an operational environment and flown in various weather conditions. The behavior of the HUD in taxiing, takeoff, climb, cruise, descent, and approach are discussed. In general, when the HUD is further refined, it should be an important development that will materially reduce the hazards inherent in the low-visibility and landing phases of flight.

122. HEAD-UP DISPLAY AREA SURVEY

Augustine, W. L., Air Force Flight Dynamics Laboratory, Wright-Paterson, AFB,
Ohio, AFFDL-TM-72-11-FGR, December 1972

This report is a survey of the HUD work being carried out by Government and industry. The report is an annotated bibliography and includes (1) a brief of recent work effort, (2) organizations performing the work, and (3) the name and address of the principle personnel responsible for the recent work.

123. HEAD-UP DISPLAY; A REPORT BIBLIOGRAPHY

Anonymous, NTIS, Cameron Station, Alexandria, Va., Search Control 049756,
November 1976

This report is the result of a machine search of the information files at DDC for documents published since 1969 relating to HUD. A total of 150 were identified.

124. HEAD-UP DISPLAY: A SAFETY CONCEPT

DeCelles, L., Burke, E. and Burroughs, K., Journal of Executive Aviation,
July 1973

As a means of upgrading, improving and supplementing head-down flight-data displays, ALPA's All-Weather Flying Committee has advocated a building-block concept in which a HUD is used for all landings under all visibility conditions from CAVU to zero-zero, a concept that would be applicable to corporate aircraft as well as airline aircraft.

125. HEAD UP DISPLAY--RADAR AND AIR-TO-AIR MODES
Aviation Week and Space Technology, May 16, 1977

126. HEAD-UP DISPLAY PROJECT PLAN (FAA/NASA)
August 1977

The program proposed is designed to identify the possible benefits, limitations, or any possible detrimental effects that an HUD may create onboard a large turbojet aircraft. A large turbojet aircraft simulator used during the early phases of the program to compare the performance of pilots in detecting deviations from the glidepath and in making correct and timely corrections under a range of adverse conditions.

127. HEAD UP DISPLAY FOR VISUAL APPROACH

Naish, J. M., 7th Annual Conference on Manual Control, University of Michigan, Ann Arbor, May 1972

128. HEAD UP DISPLAY, GENERAL SPECIFICATION FOR MILITARY SPECIFICATION
Anonymous, Department of Navy, MIL-D-8164(AS), June 1972

129. HEAD-UP DISPLAY GRAPHS OF INSTANTANEOUS FIELD OF VIEW VS. EYE DISTANCE
FOR HUD'S 121, 123, 131, 131A

Anonymous, Astronautics Corp. of America, Milwaukee, Wisconsin, October 6, 1975

130. HEAD-UP DISPLAY (HUD-121) OPERATIONAL DESCRIPTION

Anonymous, Astronautics Corp. of America, Milwaukee, Wisconsin, October 1973

131. HEAD-UP DISPLAY IN COMMERCIAL AVIATION

Phaneuf, R. J. and O'Brien, J. E., ALPA, AIAA Aircraft Systems & Technology Meeting, Seattle, Washington/August 22-24, 1977

The potential role of head-up display in U.S. commercial aviation as viewed by the airline pilot is summarized. A brief review of the development of such systems is presented with emphasis on the problems encountered and the time intervals involved. Following a presentation of a candidate head-up display, the paper analyzes the remaining problems which must be resolved before such a system is likely to see widespread usage in the U.S. airline industry.

132. THE HEAD-UP DISPLAY IN OPERATION: ONE AIRLINE'S EXPERIENCE

Short, D. C., Flight Safety Foundation, Anaheim, Calif., October 1976
Lecture series No. 71, Report No. AGARD-LS-71

133. HEAD-UP DISPLAY OPTICS

Chorley, R. A., AGARD Opto-Electronics, N75-10780, Smiths Ind. Ltd., Bishops Cleeve, England, September 1974

The factors which influence the definition of the optical system for a HUD are defined. The conflicting requirements for wide fields of view and compact, easily installed hardware discussed together with various aspects of optical performance which influence the overall display system performance. The primary reason for installing a HUD system in a military aircraft is the improved weapon-aiming capability it can provide.

134. HEAD-UP DISPLAY--RADAR AND AIR-TO-AIR MODES

Behm, B., Product Support Digest

Tells how the HUD is used in the aircraft's primary role; air superiority.

135. HEAD-UP DISPLAYS

Geisenheyner, S., Aerospace International, July/August 1976

HUD equipment is now considered to be a vital part of the navigation, flight control and weapon aiming systems of contemporary military aircraft. To some extent this has been brought about by the steadily increasing efficiency of modern ground defenses, leading to strike aircraft adopting techniques such as low-level, single-pass attacks at high speeds in order to minimize the risk of detection and time spent in the target area.

136. HEAD-UP DISPLAYS: A STUDY OF THEIR APPLICABILITY IN CIVIL AVIATION

Jenney, L. L., Malone, T. B., and Schweickert, G. A., NASA-CR-117135, January 1971

Research literature, published commentary, and supplementary information on the subject of aircraft operating problems and the HUD are analyzed. The device presents information as a collimated image in such a way that the pilot views the display and looks out the window at the same time. The general requirements governing the display's acceptance are identified as safety, practicality, and economy. The greatest potential contribution is in approach and landing. The pilot's task and his guidance and control problems are analyzed, along with takeoff, missed approach, and taxiing in very low visibilities. The applicability and usefulness of the HUD in solving these problems are outlined.

137. HEAD-UP DISPLAY STUDY

Horning, D. O., Mellander, K., Finch, D. M., Miller, A., and Horonjeff, R., California University, Richmond, Calif., Rept. No. AD-738-591, May 1971
The study objectives were to investigate effects of an HUD on a pilot's ability to see runway lights in fog. Methods of evaluation of the HUD concept under low visibility conditions were developed. Luminance of the HUD, cockpit interior, and external scene were measured with a Pritchard telephotometer at 30-minute intervals. It was concluded that the HUD unit tested would not adversely affect pilot's ability to see runway lights in fog.

138. HEAD-UP DISPLAY STUDY

Opittek, E. W., Hughes Aircraft Co., Culver City, Calif., AFAL-TR-73-215, AD-912-449L, July 1973

A study of the requirements for and the design of an advance HUD was conducted. The requirements based on use in an advanced close air support fighter included wide field of view and high brightness. It was concluded that conventional HUD techniques could not be practically used to meet these requirements. Accordingly, an advanced design utilizing holographic optics and liquid crystal display techniques was conceived and evaluated.

139. HEAD-UP DISPLAY STUDY (EFFECT OF HEAD-UP DISPLAY ON PILOT ABILITY TO SEE RUNWAY LIGHTS IN FOG)

Horning, D. O., Finch, D. M., and Mellander, K., California University, Richmond, Calif., FAA-RD-71-60, May 1971

140. HEAD-UP DISPLAY SYMBOLOGY

Orrick, W. P., Jr. and York, P. E., Naval Air Development Center, NADC-75267-40, Warminster, Pa., December 1975

This report consists of a table and accompanying illustrations which describe aircraft and weapons system functions displayed on the HUD's in the A7E, F5, F14, F15, F111A, CL84, and AV8A aircraft.

141. HEAD-UP DISPLAY SYSTEM FOR FAA'S DC-9 AIRCRAFT

Anonymous, Douglas Aircraft Co., Rept. No. 690-466C-A, June 18, 1970

142. HEAD-UP DISPLAY SYSTEM FOR CIVIL TRANSPORT

Marconi-Elliott Avionic Systems Ltd., Rochester Kent, England, Publication No. 229/685/1/K06, June 1977

This publication gives technical details of a civil transportation Head-Up display system which enters to a wide variety of cockpits and operational requirements.

143. HEAD-UP DISPLAY SYSTEMS EVALUATED

Ropelewski, R. R., Aviation Week and Space Technology, January 10, 1977

This paper explains the advantages of the HUD. It tells of some of the tests they have had with the HUD, almost all of which have been highly impressive. Also explains the data that are projected onto a semitransparent collimating lens mounted on the glare shield in front of the pilot.

144. HEAD-UP DISPLAY SYSTEMS IN MODERN AIRCRAFT

Sones, J. P., IEE Conference Publication No. 80, Displays Institution of Electrical Engineers, Loughborough U. of Tech., England, September 1971

Tells the history of the HUD. Explains the principle of the operation. Explains how the symbols are presented to the pilot. Discusses the cost of HUD as very expensive, but when you look at the system in other ways, it becomes reasonable, since it replaces several expensive instruments.

145. HEAD-UP DISPLAYS (TASK 2)

Gartner, W. B., Stanford Research Institute, Menlo Park, Calif., September 1975

146. HEADS UP DISPLAY SYSTEM USING NONPARAXIAL HOLOGRAPHIC LENSES

Oelfke, Wm. C., Naval Training Equipment Center, Orlando, Fla., Rept. No. NAVTRAEOUIPC-TN-38, September 1973

A study was made of optical systems employing holographically produced lens elements. The basic third-order aberration terms are defined for nonparaxial configurations of holographic lenses and three techniques of aberration balancing are suggested.

147. HEAD-UP DISPLAY WARNING REQUIREMENTS RESEARCH

Sheehan, D. J., United Aircraft Corp., Norwalk, Conn., No. 1232-R-0006, AD-755-736, August 1972

A study of HUD requirements was conducted to determine aircraft and mission warning information to be included in the HUD and how this information should best be presented to the pilot. A review was made of discrete warning, cautions, and advisory information available from various aircraft and mission systems. Candidate warning messages were analyzed for pilot response in each general mission phase.

148. HEAD-UP PILOTING DISPLAY

DeSury, G., Revue Technique Thomson-CAF, Vol. 6, September 1974

Following a summary of reasons for the need to present certain information in head-up fashion, two types of apparatus are described (1) displays aiding piloting in good visibility, and (2) displays assuring automatic flight surveillance while providing for manual takeover.

149. HEAD-UP SYMBOLOGY

Dekker, F. E. D., AGARD-55, 1970

This paper discusses some of the potential advantages of including flightpath vector in HUD symbology.

150. HOLOGRAM OPTICS IN HEAD-UP DISPLAYS

Close, D. H., Digest of Technical Papers, Hughes Research Labs., Malibu, Calif., May 21-23, 1974

Reflection ranges and transmission hologram configurations are considered for application in HUD based on hologram optics. Tentative design suggestions are given, covering system geometry requirements, pupil error minimization, desirable recording materials, and hologram distortion correction by an anamorphic relay lens.

151. HOLOGRAPHIC DISPLAY USING SYNTHETIC HOLOGRAM GENERATION

Wolber, W. G., Mueller, R. K., and Marom E., Bendix Research Lab., May 1971
The authors describe a concept for a dynamic 3-D display system, based upon holographic principles, which can accept data in coordinate form and synthesize a 3-dimensional display in real time. The feasibility of the physical principles underlying the display concept has been demonstrated.

152. HOLOGRAPHIC HEAD-UP DISPLAY FOR NAVAL AVIATION TRAINING

Rodeman, A. H., Mohon, W. N., and Breglia, D. R., Naval Training Equipment Center, Orlando, Florida, No. NAVTRAEOUIPC-IH-229, AD-A011 819, May 1975
This report summarizes the results of an effort to apply the technology of high-efficiency holographic lens design and fabrication to the specific case of a HUD system for use in visual simulators for aviation training. Design methods are developed. Materials research is described. Holographic lens elements are evaluated.

153. HOLOGRAPHIC HEAD-UP DISPLAY--PHASE II

Harris, T. J., Schools, R. S., Sincerbox, G. T., Hanna, D. W., and Delay, D. G., IBM Corp., Poughkeepsie, N.Y., Rept. No. AD-703-683, March 1970
This report describes the results of a continuation of the development work initiated in Phase 1 of the contract on displays of this type using sideband or carrier-frequency Fresnel holographic recorded images. The goals of phase 2 were to study the various modes and techniques derived in phase 1 and other possibilities, to select the approach that offered the best potential for use in Navy carrier-based aircraft, and to build a laboratory model of this selected system.

154. HOLOGRAPHIC LENS FOR PILOT'S HEAD-UP DISPLAY

Close, D. H., Au, A., and Graube, A., Naval Air Development Center, Warminster, Pa., Rept. No. N62269-73-C-0388, AD-787605, August 1974

This contractor's report, prepared by Hughes Research Lab., Malibu, Calif., describes work done from April 1973 to April 1974 on the development of a hologram lens system for a HUD. The work includes a parametric analysis study, preliminary system design, development of a red-sensitive hologram recording material, and experiments on a hologram lens element for a HUD having a 25° field of view, a 25-inch eye relief, and a 3-inch-high by 5-inch-wide exit pupil.

155. HOLOGRAPHIC LENS FOR PILOT'S HEAD-UP DISPLAY

Close, D. H., Au, A., and Graube, A., Naval Air Development Center, Rept. No. AD-787-605, N75-15650, April 1, 1975

This contractor's report by Hughes Research Lab., Malibu, Calif., describes the work done from July 1974 to October 1974 on the development of a hologram recording apparatus with a fringe control system for 16-inch diameter, 50° off-axis, symmetric transmission holographic lens for pilot's HUD.

156. HOLOGRAPHIC LENS FOR PILOT'S HUD--PHASE III

Au, A., Graube, A., and Cook, L. G., Hughes Research Labs., Malibu, Calif., AD-2029-945, February 1976

The report describes work on the fabrication of the full-scale holographic lens for a wide field of view (FOV) HUD system. The basic system parameters are a 25° FOV, a 25-inch eye relief, and a 3-inch high by 5-inch-wide exit pupil. The work includes a design study of reflection hologram collimator/combiner and the fabrication and test of a T90-N8-21.9 transmission hologram lens.

157. HOLOGRAPHIC OPTICAL ELEMENTS

Colburn, W. S., Zech, R. G., and Ralston, L. M., Harris Electro-Optics Center of Radiation, Technical Rept. AFAL-TR-72-409, AD-760-561, 1973

The significance of this research is the evaluation and characterization of possible recording materials for holographic optical elements. Seven recording materials were evaluated for use as holographic optical elements through measurement of holographic sensitometric and readout parameters and investigation of their environmental stability.

158. HOW AN AIRLINE PILOT WOULD USE HUD

Terhune, G. J. Jr., ALPA, All-Weather Flying Committee at the PWA--Sundstrand HUD Symposium, Vancouver, Canada, September 7-9, 1977

The information now available to a pilot in the final stages of a see-to-land approach is seriously deficient. Four HUD elements would have the most favorable effect on the information gaps: Horizon, Flightpath Index, Velocity Vector, and an instrument or visual Aiming Point. Using these elements in a "full IFR" HUD, the pilot would achieve better performance and reliability in guidance and control of the aircraft in all phases of the approach and landing or go-around.

159. HUD SYMBOLOGY

Terhune, G. J. Jr., ALPA All-Weather Flying Committee, February 1977

Upgraded recommendations by ALPA for HUD Symbology to meet categories I, II, and III requirements are given.

160. HUMAN ENGINEERING FOR THE AIR FORCE CONTROL-DISPLAY PROGRAM

Synder, T. A. and McTee, A. C., Air Force Flight Dynamics Lab., Wright-Paterson AFB, Ohio, AFFDL-TR-72-109, AD-754-916, June 1972

A research program which addresses each of two interface problems to be considered in the conduct of advanced control-display research within the system context; namely, the manager/information systems interface and the pilot/aircraft interface. Activities included an investigation to explore the potential of an on-line terminal with a CRT and printer.

161. HUMAN ENGINEERING GUIDE TO EQUIPMENT DESIGN

Anonymous, Department of Defense, 1972

162. HUMAN FACTORS ENGINEERING FOR HUD: A REVIEW OF MILITARY SPECIFICATIONS AND RECOMMENDATIONS FOR RESEARCH

Egan, E. E. and Goodson, J. E., Aerospace Psychology Dept., Naval Aerospace Medical Research Lab., 1976

163. IFALPA FLIGHT TEST REPORT

Ertzgaard, J. H., The Thompson-CSF TC-121, Bretiguy, France, November 20, 1975

164. THE IMPACT OF ADVANCING TECHNOLOGY ON THE EVOLUTION HEAD-UP DISPLAY SYSTEMS

Smith, J. H., Conference on Guidance and Control Displays, Paris, France, AGARD-CP-96, October 1971

This paper briefly outlines the history of Electronic HUD systems as applied to military aircraft and considers the various major developments which have been demanded by successive avionics system requirements and the way in which advancing technology, mainly in the area of components, has allowed these increasingly stringent requirements to be implemented. Reference is also made to the most recent developments where computation for weapon delivery, or other purposes, can be provided as an integral facility within the HUD electronics unit.

165. THE IMPACT OF ELECTRONIC DISPLAYS ON AIRCRAFT CONTROL

Lowry, P., AGARD 58, N70-23026-10-21, January 1970

This paper explains the advances in aircraft automation and cockpit display technique now being introduced.

166. THE IMPACT OF OPTO-ELECTRONICS UPON AVIONICS . . . DEVELOPMENT AND APPLICATION OF ELECTRO-OPTICAL EQUIPMENT WITH EMPHASIS ON SYSTEM DESIGN

Stringer, F. S., AGARD LS-71, September 1974

The military applications of electro-optical equipment are discussed. The advantages of HUD are compared with those of head-down displays.

167. IMPROVED DISPLAY SUPPORT FOR FLIGHT MANAGEMENT DURING LOW VISIBILITY APPROACH AND LANDING

Gartner, W. B. and Baldwin, K. M., NASA-CR-73495, TR386070-01, November 1970

A preliminary evaluation of an ILS-independent, pictorial runway perspective display concept was conducted. The improvement which might be realized in the accuracy of flight management task performance was determined.

168. INDEX TO SYMBOLS--ALPA--HUD

DeCelles, J. L., Attachment to letter from ALPA to NASA Ames, October 26, 1971
This symbology provides all, or at least very nearly all, the flight data required for conducting landing approaches of all types in all kinds of visibility, e.g., VFR, IFR, precision, nonprecision, Cat I, II, and III and even two-segment glide slope approaches.

169. THE INFLUENCE OF WINDSHEAR ON AIRCRAFT IN APPROACH

Anonymous, Thompson-CSF, Paris, France, 1976

This report deals mainly with the studies of various windshears, the affects on an aircraft, and the potential benefits derived using a HUD presentation during such encounters.

170. INFORMATION TRANSFER IN ALL-WEATHER OPERATION

Naish, J. M., Shell Aviation News, No. 396, 1971

This paper attempts to broaden the basis for evaluating an aircraft all-weather flight system. The influence of the pilot on overall reliability is considered in terms of the balance of supply and demand in the information process of the complete man-machine system.

171. INITIAL FLIGHT AND SIMULATOR EVALUATION OF A HEAD-UP DISPLAY FOR STANDARD AND NOISE ABATEMENT VISUAL APPROACHES

Bourquin, K., Palmer, E. A., Cooper, G., and Gerdes, R. M., NASA-Ames Research Center, Moffett Field, Calif., NASA-TM-X-62187, February 1973
A preliminary assessment was made of the adequacy of a simple HUD for providing vertical guidance for flying noise abatement and standard visual approaches in a jet transport. Preliminary flight and simulator data are presented, and problem areas that require further investigation are identified.

172. INSTRUMENTATION DISPLAYS FOR FUTURE NAVAL AIRCRAFT

Mulley, W. G., AIAA Paper 75-599, Digital Avionics System Conference, Boston, Mass., April 2-4, 1975

The advanced integrated modular instrumentation system (AIMIS) is described. The functions of the display indicators and the electronics units are outlined. Other features of the system mechanization and improvements in operational effectiveness over present cockpit instrumentation are noted.

173. INTEGRATED ADVANCED ELECTRONIC DISPLAY SYSTEM

Shovolt, R., 2nd Advanced Aircrew Display Symposium, General Electric Co.

174. INTEGRATED INFORMATION PRESENTATION AND CONTROL SYSTEM STUDY

Zipoy, D. R., et al., Force Flight Dynamics Lab., Wright-Patterson AFB, Ohio, Vol. I and II, August 1970

The analytical methods used to develop control display concepts, a limited degraded mode analysis, and their detailed results are presented in this report.

175. INTEGRATED MODULAR DISPLAY SYSTEM--FOR NAVAL AIR COMBAT FIGHTER

Weihrauch, M., Advanced Aircrew Display Symposium, 2nd, Patuxent River, Md., (ATS-41401 20-06), April 23-24, 1975

A description is presented of a display system which includes all functional elements of the Advanced Integrated Modular Instrument System (AIMIS). Attention is given to the HUD, horizontal situation display, multipurpose displays, and a programmable display processor.

**176. INVESTIGATION INTO THE OPTIMUM USE OF ADVANCED DISPLAYS IN FUTURE
TRANSPORT AIRCRAFT**

Hillman, R. E. and Wilson, J. W., Hawker Siddeley Aviation, British Aircraft Corp., 1976

Advanced displays, specifically in the form of CRT's, have shown us that it is feasible to reconfigure the engine and system instrumentation and controls of a four-engined, three-crew transport aircraft and achieve a standard that is comparable with a simpler two-engined two-crew aircraft. The inherent flexibility of electronic displays indicate that further significant improvements are possible through the suppression of untimely or unnecessary information and the consequent integration of relevant data on to a smaller display area. The same flexibility encourages us to believe that electronic ADI's and HSI's can be evolved which include all the required flight and navigation information in a way that is as operationally attractive as, but substantially different from the current conventional displays. It would be imprudent of us to pre-judge the assessment that is now running and which will determine, if possible, the effect of advanced displays on crew workload--but our subjective impressions are that the real potential both in human factors and engineering terms is steadily becoming more obvious. If we are right, the program will need all the support that it can get from Airlines, Airworthiness authorities, equipment manufacturers and those involved in the definition of international standards.

177. INVESTIGATION OF HOLOGRAM TECHNIQUES

Leith, E. N. and Opatnieks, J., Michigan Univ. Ann Arbor Inst. of Science and Technology, Rept. No. 16730-87-F, AD-902-937, July 1972

This report gives the results of the summary of the work done in the past years. Reported second are investigations of three areas of holography applications: three-dimensional light-line sights for aircraft HUD; three-dimensional displays for air traffic control; and holographic information storage and display for aircraft. Third, the investigation of magnesium bismuth for its usefulness as an erasable recording material. Fourth, summaries of several research efforts are presented.

178. INVESTIGATION OF HOLOGRAPHIC TESTING TECHNIQUES

Vest, C. M., Ribbens, W. R., Sweeney, D. W., Leith, E. N., and Varner, J. R., Michigan Univ. Ann Arbor Inst. of Science and Technology, Rept. No. 24200-28-F, AD-734-408, December 1971

The investigations described include the following: (1) interferometric detection of microcracks; (2) detection of the bonds in honeycomb sandwich structures; (3) real-time monitoring of stress-corrosion cracking; (4) interferometry of three-dimensional, refractive-index fields; (5) measurement of vibrational amplitudes; (6) holographic contouring; (7) optical determination of rms surface roughness; and (8) nondestructive inspection of shell casings and projectiles.

**179. INVESTIGATIONS ON THE FEASABILITY AND INTERPRETABILITY OF ELECTRONIC
DISPLAYS: INVESTIGATIONS ON THE EFFECTIVENESS OF BRIGHTNESS CODING AND COLOUR
CODING OF DISPLAY ELEMENTS**

Beyer, R., Schenk, H. D., and Zietlow, E., DLR FB 71-57 Deutsche Luft und Raumfahrt, N73-15484, DLR FB 71-57, 1971

The work described here is a contribution to the study of the coding of display elements in electronic displays. It compares the effectiveness of brightness coding with that of color coding.

180. LANDING AIDS FEASIBILITY INVESTIGATION

Anonymous, McDonnell Aircraft Co., St. Louis Mo., MDC-A3618, AD-B006-900L, September 1975

This report documents the AV-8A landing aids feasibility investigations. The effort included studies, development, and manned simulation to define landing aids.

181. LASER ACQUISITION DEVICE (LAD)

Dodd, D. A., Armament Development and Test Center, Eglin AFB, Fla., Rept. No. ADTC-TR-74-71, AD-531-008L, August 1974

182. LIGHT-LINE VISUAL LANDING HUD EVALUATION--PHASE I

Tapia, M. H. and Intano, G. P., USAE Instrument Flight Center, Randolph AFB, Tex., IFC-TR-76-1, (N76-292294A), January 1976

This report discusses the evaluation of the Light-Line HUD being conducted to investigate HUD systems/concepts to aid the pilot in maintaining a specified vertical path during visual landings. Analysis indicates that the light-line HUD, as presently designed, was not considered satisfactory for inclusion in USAF aircraft.

183. LOSS OF VISUAL CUES DURING LOW VISIBILITY LANDING

Anonymous, FAA AC 91-25A, June 1972

184. LOW VISIBILITY LANDING PILOT MODELING EXPERIMENT AND DATA--PHASE I

Gressang, R. V., Stone, J. R., Kugel, D. L., and Pollard, J. J., AFFDL-TR-75-41, October 1974

185. LOW VISIBILITY LANDING PILOT MODELING EXPERIMENT AND DATA--PHASE II

Anonymous, Rept. No. AFFDL-TR-75-57, Air Force Flight Dynamics, Wright-Paterson AFB, Ohio, August 1975

This report describes an experiment to collect data for modeling pilot behavior during low visibility approach and landing. The data are presented in a form suitable for use in forming a pilot model of the optimal control type.

186. MANUAL APPROACH PERFORMANCE USING A SIMPLE AIRBORNE VASI HUD

Brown, A. D. and Ginn, S. B., Royal Aircraft EStablishment, Rept. No. 73080, TR-71141, AD-917-418L, September 1973

This report describes an investigation into the effectiveness of a simple airborne VASI HUD as a clear weather approach aid. The results obtained clearly demonstrated the usefulness of such a display, stabilized in pitch and roll, for defining a safe approach path to a runway devoid of ground aids. The effects of pitch gearing on flightpath stability are discussed, and a comparison is made between inertial and vertical gyro attitude sensors for stabilizing the display. A brief summary of relevant aircraft accident statistics is presented as evidence in support of the case for using HUD's in civil airliners.

187 THE MARCONI-ELLIOTT HEAD-UP DISPLAY

Campbell, J., FARL Proposal No. 262/050, Issue 1, June 1974

188. MATERIALS FOR HOLOGRAPHIC OPTICAL ELEMENTS

Colburn, W. S. and Dwyer, J. C., Technical Report AFAL-TR-73-364, November 1973

189. MATERIALS FOR HOLOGRAPHIC OPTICAL ELEMENTS

Close, D. H. and Graube, A., Hughes Research Labs., Malibu, Calif., AFML-TR-2671 AD771-775, 1973

An experimental program was conducted to develop a hologram recording material sensitive at 545 nm, suitable for producing high-quality holographic optical elements on spherical plastic visor substrates. Emphasis was placed on dye sensitized dichromated gelatin. Experiments verified the use of the surface grating equation for calculating external reconstructed ray directions from thick holograms, compared theoretical and observed angular sensitivity for a standard dichromated gelatin film, and evaluated interferometric and Hartman tests of asymmetric holograms to monitor film stability.

190. THE MECHANISM OF HOLOGRAM FORMATION IN DICHROMATED GELATIN

Curran, R. K. and Shankoff, T. A., Appl. Opt. 9, 1651, 1970

191. THE MISSED APPROACH

May, J. T., Air Line Pilots Association, Kansas City, Kansas, January 21, 1976

192. MONOCULAR VISUAL CUES AND SPACE PERCEPTION DURING THE APPROACH TO LANDING

Riordan, R. H., Space Medicine, Munich, Germany, Sept. 18, 1973

This paper describes a system useful to pilots for approach, landing, and for navigation. Attitude, airspeed, altitude, and spatial location as derived both from ground stations and aircraft sensors are presented in a uniquely useful and integrated analog display which is projected through the windscreens and superimposed on the real world view.

193. A MULTI-PURPOSE WIDE FIELD, THREE DIMENSIONAL HEAD-UP DISPLAY FOR AIRCRAFT

LaRussa, J. A., Farrand Optical Co., Valhalla, N. Y. AGARD-CP-96

This paper describes a system useful to pilots for approach and landing and for navigation. Attitude, airspeed, altitude, and spatial location as derived both from ground stations and aircraft sensors are presented in a uniquely useful and integrated analog display which is projected through the windscreens and superimposed on the real world view. The display is a true three-dimensional roadway in the sky, down which the aircraft can be flown either for navigation or to a touchdown on the runway. The three-dimensional analog displays reduces pilot interpretation time and thereby provides for better aircraft control.

194. NAVY TECHNICAL EVALUATION OF THE ELLIOTT TYPE 546 HEAD-UP DISPLAY

Field, P. B. and Smullen, R. R., Naval Air Test Center, Patuxent River, Md., NATC-WST-69R-74, AD-921-800L, July 1974

The Elliott Type 546 HUD was installed and flight tested to determine compatibility and capability in the TA/A-4 airplane. General improvement in pilot-airplane interface, improvements in both manual and computed weapon delivery accuracy, provisions for an air-to-air mode, and five other enhancing characteristics provided significant advantages for accomplishing the visual attack mission.

AD-A054 246 NATIONAL AVIATION FACILITIES EXPERIMENTAL CENTER ATL--ETC F/G 1/4
HEAD-UP DISPLAYS: A LITERATURE REVIEW AND ANALYSIS WITH AN ANNO--ETC(U)
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195. NEW CONCEPTS OF VISUALIZATION FOR AIRCRAFT---INSTRUMENT PANEL DISPLAY INTEGRATION

Coussediere, M., Thomson-CSF, Paris, France, October 1973

The flexibility of electronics makes it possible to exhibit according to the pilot's choice, the visualization best adapted for each phase of the pilot's choice, the visualization best adapted for each phase of flight, whether for head-up or head-down displays. An operational description is given, and technical characteristics and examples of apparatus that has been developed are described.

196. NEW DEVELOPMENTS IN THE DESIGN OF HOLOGRAPHIC OPTICS

Latta, J. N. and Fairchild, R. C., Proceedings of the Seminar on Applications of Geometrical Optics, Society of Photo-optical Instrumentation Engineers, Redondo Beach, Calif., 1973

197. NEW ELECTRONIC DISPLAY SYSTEMS FOR AIRCRAFT INSTRUMENT PANELS

Coussediere, M., AGARD Electron, Airborne Displays, (N76-17107 08-02) December 1975

Concepts for new electronic display systems for aircraft instrument panels were proposed, emphasizing the need to integrate and synthesize the information presently given by a number of different instruments. The report explains the systems that would present the advantages.

198. A NEW HEAD UP PILOTING DISPLAY MEDICO-PHYSIOLOGICAL REMARKS

Lavernhe, J., Dr., Centre Medical Service of Air France, March 1975

This report makes a comparison between perceptual aspects of a HUD and those associated with traditional IMC guidance.

199. NIGHT VISUAL APPROACHES PILOT PERFORMANCE WITH AND WITHOUT A HUD

Palmer, E. A., NASA--Ames Research Center, Moffett Field, Calif., N72-33024, NASA-TM-X-62188, October 1972

Simulated night visual approaches were flown into two different airports with and without a HUD in a transport aircraft. This report discusses the difference when using the HUD and when not using the HUD.

200. THE OPEN VISUAL LOOP IN PITCH

May, T., TWA MEC All Weather Committee, June 1974

201. OPERATIONAL REQUIREMENT FOR DISPLAY SYSTEM FOR CONTROL AND SUPERVISION OF THE AIRCRAFT FLIGHTPATH

Anonymous, 31st IFALPA Annual Conference, Rept. No. 76C129, November 1975

202. OPERATING A HUD

Wieser, M. F., Shell Aviation News No. 411, 1972

The paper discusses data accumulated by a qualified pilot during actual operation of a Nabisco executive jet falcon, using a HUD. The functional aspects of the system are demonstrated by motion pictures taken during a low-visibility runway approach.

203. OPTICAL DEVICE STUDIES: FLIGHT DISPLAYS

Stein, K. J., Aviation Week and Space Technology, January 1974

A brief description of a new device (an oculometer) which uses the corneal reflection of infrared light to track eye motion.

204. OPTICAL HOLOGRAPHY

Collier, R. J., Burckhard, C. B., and Lin, L. H., Academic Press, New York, 1971

205. THE PERI-HUD

Lewis, C. J. G., Marconi-Elliott Avionics, LTD, Rochester Kent, England, April 24, 1975

Discusses the use of the Peri-HUD; enables piloting, navigation and weapon-aiming symbols to be projected ahead of the pilot by equipment which occupies less space in the cockpit, and obtrudes far less into the instrument panel, than is possible with the present form of display. Discusses the two main advantages of the periscope optic.

206. A PILOT-CONTROLLED OUT-THE-WINDSHIELD VISUAL DISPLAY USING A CONVENTIONAL ATTITUDE DIRECTION INDICATOR

Crosbie, R. J., Passavanti, L., and Fessenden, E., Naval Air Development Center, Warminster, Pa., NADC-CS-7123, 73-00303, December 1971

207. PILOT DISPLAYS IN AVIONIC SYSTEMS OF THE FUTURE

McKinlay, W. H., Royal Aeronautical Society, Canadian Aeronautics and Space Inst., and American Inst. of Aeroanutics and Astronautics, Anglo-American Aeronautical Conference, 11th, London, England, September 1969

208. PILOTED FLIGHT SIMULATOR

Sawtell, R. E., Miles, J. H., and Frampton, R. F., Rept. No. TRC-BR-17054, October 1970

The main technical features of the general purpose piloted flight simulator are described. The report includes description of the fixed-base cockpit, instruments, HUD, controls feel system, the visual display system, and the present analogue computers. A brief history of the simulator is given, present limitations mentioned, and future developments outlined.

209. PILOT FACTORS CONSIDERATIONS IN SEE-TO-LAND

Swartz, W. F., Condra, D. M., and Madero, R. P., Bunker Ramo Corp., Westland Village, Calif., Rept. No. AFFDL-TR-76-52, May 1976

The aviation industry is employing a building block approach with respect to aircraft avionics, in general, and automatic flight control system, in particular, to move systematically from categories I through II to category III operations.

210. PILOTING TECHNIQUES AND FLYING QUALITIES OF THE NEXT GENERATION OF AIRCRAFT

Wanner, J. C. L., Aeronautical Journal Vol. 77, December 1973

Outlines accidents, how and when incidents occur, the tasks of the pilot, analysis of the pilot's work, gives an example of the pilot's work, the definition of the workload, etc.

211. PILOT PERFORMANCE DURING A SIMULATED STANDARD INSTRUMENT PROCEDURE TURN WITH AND WITHOUT A PREDICTOR DISPLAY

Kreffeldt, J. G. and Wempe, T., NASA, In MIT Proc. of the 9th Annual Conference on Manual Control, N73-17118, NASA-TM-X-62201, 1973

A simulator study was conducted to measure the effectiveness of predictor information incorporated into a CRT display of a computer-simulated aircraft's horizontal and vertical situation. Results show that the display with the predicted ground track was markedly and significantly superior to the display without the information, and that the subjects were generally satisfied with this type of information.

212. PILOT PERFORMANCE WITH A SIMULATED ILS-INDEPENDENT PICTORIAL DISPLAY

Palmer, E. A., and Wempe, T., 7th Annual Conference on Manual Control, 1972

As part of a general investigation of the effectiveness of pictorial displays for manual control and monitoring of aircraft approaches and landings, a simulator study was conducted in which pilot performance with three pictorial displays was evaluated. These displays differed in the type of guidance symbology added to the basic perspective runway display. The results indicate that for pictorial displays with added guidance symbology, there was a marked improvement in pilot performance compared to results of a previous study in which the display consisted of only a runway image and aircraft attitude.

213. PILOT'S SAFETY PROBLEM IN CATEGORY II OPERATIONS AND POTENTIAL CONTRIBUTION OF HUD

Morrall, J. C., Royal Aircraft Establishment, Farnborough, England, TR 66195, 1966
This report aims to fulfill two main functions; firstly, it highlights what is believed to be the main safety problem in current bad weather landing and secondly, it presents the results of initial flight trials with a HUD which show that this aid has great potential value for category II operations.

214. POSSIBLE USE OF FAIL-PASSIVE AUTOLAND SYSTEMS FOR LANDING IN 700 RVR CONDITIONS

Anonymous, ALPA Tape Recording, August 28, 1973

215. PRELIMINARY FLIGHT TESTS OF THE HUD IN THE VISUAL APPROACH

Naish, J. M., Douglas Aircraft Co., IRAD Line Item Description No. DAC-34-74-R322, Rept. No. MDC J6782-1, June 1975

216. PRELIMINARY REPORT ON AIRLINE PILOT SCAN PATTERNS DURING SIMULATED ILS APPROACHES

Spady, A. A., Jr., NASA Report No. SP-416, October 1976

A series of ILS approaches using Boeing 737 simulator have been conducted. The test matrix included both manual and coupled approaches with and without atmospheric turbulence in category II weather. A nonintrusive oculometer system was used to track the pilot's eye-point-of-regard throughout the approach. The results indicate that, in general, the pilots use a different scan technique for the manual and coupled conditions. The data show a high degree of consistency among pilots for both the quantitative data and the qualitative data (pilots' opinions).

217. PRESENTATION OF THE DATA REQUIRED FOR TAKEOFF AND LANDING--PILOT PERFORMANCE MODEL FOR COCKPIT DISPLAY DEVELOPMENT

Wanner, J. C., AGARD, Symposium on takeoff and landing, Edinburgh, Scotland, CP-160, April 1974

Description of a study leading to the development of a cockpit display, the main part of which is designed for takeoff and landing phases. On the basis of a study of pilot behavior during takeoff and landing, a pilot model was constructed. A study with the aid of this model made it possible to develop a device which could serve as a future cockpit display in which the part designed for takeoff and landing phases is a HUD presenting the ground track of the air velocity vector and the total climb angle.

218. PREVENTION OF AIRCRAFT LOSS OF CONTROL USING A SIMPLE HEAD-UP DISPLAY

Skelton, G. E. and Sulzer, R. L., NAFEC, Atlantic City, N.J., Rept. No. FAA-NA-71-9, June 1971

To evaluate the concept of a simple HUD as an aid to noninstrument-rated pilots of encountering reduced flight visibility conditions, two versions of such a display were flown by six pilots. Given either of the HUD instruments and a partial panel of basic instruments, plus a brief indoctrination in the use of the HUD, the pilots showed marked improvement in preservation of aircraft control.

219. PROCEEDINGS OF A SYMPOSIUM ON VISUALLY COUPLED SYSTEMS: DEVELOPMENT AND APPLICATION

Birt, J. A. and Task, H. L., Aerospace Medical Div., Brooks AFB, Tex., Rept. No. AMD-TR-73-1, AD-916 5722, September 1973

This report discusses how a visually coupled system integrates the natural visual and motor skills of an operator visually searches for, binds, and tracks an object of interest.

220. PROGRAMMABLE HEAD-UP DISPLAY (HUD 120) APPENDICES I-V

Anonymous, Astronautics Corp. of America, Milwaukee, Wisconsin, AD-B007975L, June 1974

This report describes all the technical design details of the programmable HUD system.

221. PROPERTIES AND DESIGN OF THE HEAD-UP DESIGN

Naish, J. M., Douglas Aircraft Co. & Division Douglas Paper 4951, MDC-J-1409, February 1970

This report discusses the properties resulting from the application of results and other rules relating to design, location, and control of symbols, allow the average user to learn very quickly, and to reach a relatively high level of performance without overconcentration.

222. A PROPOSAL FOR AN AIRBORNE VASI

Campbell, J., Marconi-Elliott Avionic Systems Limited, Rochester, Kent, England, Rept. No. 262/08, April 1974

This describes a program to develop a flyable airborne VASI (HUD), using light-emitting diodes (LED) which would be suitable for large transport category aircraft.

223. A PROPOSAL FOR PRE-PROCESSING, REDUCTION, AND SELECTION OF VISUAL INFORMATION IN AIRBORNE FLIGHT SIMULATION

Gartner, K. P., 7th Annual Conference on Manual Control, NASA SP-281, June 2-4, 1971

This paper explains all of the complications the pilot holds. Tells about the need for a selection of the most suitable data to be presented to the pilot in order to facilitate the interpretation of flight situations and to optimize the decision process with regard to the displayed information.

224. THE QUESTION: TO LAND OR NOT TO LAND

Glines, C. V., Airline Pilot, April 1977

The recommendations of NTSB following a study on two types of approved type accidents and comments on those recommendations by ALPA are given.

225. RASTER HUD FOR A-7E

Anonymous, Flight International, March 26, 1977

This paper explains how the HUD will form part of the Vought-developed forward-looking infrared (FLIR) night-vision. The flight, navigation and weapon-aiming symbols will be shown as on a conventional system, but there will also be a TV-like raster display on which an outside-world picture can be superimposed.

226. RASTER HUD---HUD RESEARCH AND DEVELOPMENT

Anonymous, Aviation Review, January 1976

Current areas of research and development in electronic HUD for strike-fighters which combine symbology with synthetic video are discussed. Special attention is directed to electro-optical sensors to provide synthetic pictures of the outside world under low-light and low-visibility conditions, including low-light-level television and forward-looking infrared detectors.

227. A RATIONAL PROGRAM FOR LOW VISIBILITY LANDING

DeCelles, J. D., Burke, E. J., Roberts, W. B., and Burroughs, K., NTSB Approach and Landing Accident Prevention Forum, October 24, 1972

228. RATIONAL STUDY OF AIRCRAFT PILOTING

Klopfstein, G., Intrados Magazine, 1976

229. A REAL WORLD SITUATION DISPLAY FOR ALL-WEATHER LANDING

DeCelles, J. L., Burke, E. J., and Burroughs, K., ALPA All-Weather Flying Committee, Edinburgh, Scotland, AGARD-CP-105, June 1972

This paper describes a flight data display for use in aircraft approach and landing under all conditions of visibility from CAVU to zero-zero. In its simplest form, it provides airborne self-contained glidepath guidance for use in visual flight conditions, and in its most sophisticated form it provides a total information for manual landing, or for monitoring automatic landings, and rollout during zero visibility conditions. The authors contend that HUD of symbology similar to that described is urgently required for see-to-land approaches and will be essential for pilot acceptance of automatic landings in actual nonvisual conditions.

230. RECENT DEVELOPMENTS IN LOW-COST HUD

Stormo, M. E., Flight Safety Foundation, Annual Business Aircraft Safety Seminar, 14th, Washington, D.C., May 13-14, 1969

231. RELIABILITY ANALYSIS OF MICROCIRCUIT FAILURES IN AVIONICS SYSTEMS (RAMFAS)

Dohm, K. L., McCammack, R. J., and Utz, T. E., McDonnell Aircraft Co., St. Louis, Mo., TR-76-3, AD-A021-428, January 1976

The report describes the 12-month study of the RAMFAS program. The objectives of this RAMFAS program were (1) to assess the reliability of current microcircuit technology in the avionics environment; (2) to assess the validity and effectiveness of presently used techniques for microcircuit procurement, screening quality assurance, and reliability prediction. The report documents the analysis of 308 devices out of 438 microcircuit removals from 31,393 microcircuits assembled, tested and shipped to the field in 39 HUD and 35 IBS F15 equipments.

232. REPORT ON APPROACH AND LANDING ACCIDENT PREVENTION FORUM

Anonymous, National Transportation Safety Board, NTSB-AAS-73-2, October 24-25, 1972

233. REQUIRED PILOT CUES AND DISPLAYS FOR TAKEOFF AND LANDING

Wanner, J. C., AGARD-CP-160, January 1975

A model of pilot behavior during the takeoff and landing phases of flight was used to determine the necessary cues and in turn the parameters which have to be displayed in order to minimize the pilot workload and improve flight safety. This paper discusses the uses with the two parameters.

234. REQUIREMENTS FOR HOLOGRAPHIC DISPLAYS

Jacobson, A. D., Information Display, November/December 1970

Discussion of holography is presented with emphasis on the displays application. This paper includes a brief tutorial discussion of holography including a description of the requirements and limitations of the holographic process. Anticipated hologram display applications such as hologram motion pictures and hologram TV are discussed. Examples of the various applications are listed and the state-of-the-art is defined. The problems associated with the implementation of hologram display is presented.

235. RESEARCH STUDIES FOR THE DEVELOPMENT OF DESIGN CRITERIA FOR SENSOR DISPLAY SYSTEMS

Anonymous, Hughes Aircraft Com., Culver City, Calif., March 1976

236. RESULTS OF F-14A HUD SYMBOLOGY SIMULATION

Ryan, J. G., Naval Air Development Center, Johnsville, Pa., Rept. No. NADC-SD-6940, AD-861-735L, June 1969

NAVAIRDEVCEN developed a simulation of F14A HUD. The simulator was programmed to dynamically demonstrate HUD symbology and formats in the carrier-landing and air-to-ground weapon delivery modes. The symbols used in this demonstration were basically those proposed for the F14A aircraft.

237. RESULTS OF THE INVESTIGATION OF DIFFERENT EXTRAPOLATION DISPLAYS

Dey, D., Advanced Study Institute on Displays & Controls, A72-41402 21-05,
March 1971

Experiments on five subjects show that the steering reliability can be increased and the "lapse time" can be reduced when a prediction display is used in manual aircraft control. It is concluded that a prediction display gives the pilot more exact faster information about the action of his stick signals and thereby assists in generating an optimal-time steering operation.

238. A REVIVAL OF THE "ONE MAN BAND"

DeCelles, J. L., ALPA All-Weather Flying Committee, ALPA Air Society Forum,
July 1969

239. A REVOLUTIONARY ALL-WEATHER HUD

Chopping, D., Interavia Previews the Thomson-CSF, June 1976

This article highlights the development of the TC 125 based on tests in which the TC 121 was employed as a research tool. The displays used accommodate all corrections being made in the natural direction as opposed to the requirement of interpretation prior to correction of a conventional instrument display.

240. ROLE OF HEAD-UP DISPLAY IN INSTRUMENT FLIGHT

Barnette, J. F. and Intano, G. P., USAF Instrument Flight Center, Randolph Field, San Antonio, Tex., Rept. No. LR 76-2, AD-A030075, August 18, 1976

A pilot factor survey was conducted of the F111D, A-7D, and F15 aircraft HUD's. This survey indicated that HUD's have the potential for use as a primary flight reference system, but there are problems and ambiguous areas which require solution prior to so doing. These include (1) failure of the monitoring system, (2) symbology and format requirements, (3) established procedures and techniques, (4) clutter, (5) effects of changing external environment such as ambient light and cloud conditions, and (6) transitioning from instrument panel to HUD and back again.

241. ROTATABLE HUD WITH COORDINATE REVERSAL CORRECTIVES

Kinder, F. A., Patent Application, copy available from NTIS, 1974

The patent application relates to a rotatable HUD system provided to furnish target coordinate information to the pilot of an aircraft. A small CRT is used for the display, and the scene is viewed through a holographic lens so that the display appears at infinity focus.

242. SAFETY ASPECTS OF HUD

Penney, N., Flight Safety, Vol. 2, December 1968

Six safety aspects of HUD are discussed, including redundancy capabilities, elimination of the transition from head down to head up at a critical time in the approach, flightpath guidance on a go around, increased safety without glide slope aid, guidance during takeoff especially rotation and lift-off, overcoming eye-scanning limitation and solution to limited flight panel space.

243. SCHEDULE VERSUS SAFETY - CHOOSING WEATHER MINIMUMS

DeCelles, J. L., All-Weather Flying Committee, 1976

- 244. SIMULATION AND FLIGHT EVALUATION OF A HUD FOR GENERAL AVIATION**
Harris, R. L., Sr., Society of Automotive Engineers Business Aircraft Meeting, Wichita, Kansas, SAE paper 740347, April 2-5, 1974
A landing-site indicator (LASI) has been devised as a relatively simple HUD to show the pilot the magnitude and direction of the aircraft's velocity vector superimposed on the pilot's view of the landing area. One hundred and sixty landings were performed in a fixed-base simulation program by four pilots with and without the LASI display. The document discusses the results.
- 245. A SIMULATOR ASSESSMENT OF THREE HEIGHT PRESENTATIONS ON A HUD**
Oldfield, D. E. and Horner, R. M., GB RAE Tech Memo Avionics, 1972
- 246. A SIMULATOR EXPERIMENT TO INVESTIGATE A LATERAL RATE FIELD DISPLAY**
Wewerinke, P. H., National Aerospace Lab., Amsterdam, Netherlands, NLR-TR-74093-U, N76-22195, June 14, 1974
To assess the use of linear rate field displays with respect to their alerting, directing, and tracking functions the results of an experimental program in a realistic task situation; namely, a lateral position control task in the presence of lateral gust disturbances for a fighter aircraft, are presented. Results of two displays are included in the experimental setup.
- 247. SIMULATOR INCLUDING IMPROVED HOLOGRAPHIC HUD SYSTEM**
Derderian, G., Department of the Navy Washington, D.C., Patent Application DAT-APPL-518 000/GA, October 1974
The patent application describes a simulator including an improved holographic heads-up display system in which the projection of images, via a plurality of slide projectors, through several light-ray channels or paths, are controlled by a polarizer light valve associated with each respective channel, and the output or outputs of the channels dependent upon the on-off conditions of the several light valves, is passed through a holographic lens as a window to the eye of an observer. A further aspect of the invention contemplates the provision of a means of vehicular control connected to recording charts to compare actual trainee controls movement to proper movement per exercise.
- 248. A SIMULATOR STUDY OF THE FEASIBILITY OF SIMPLIFYING A COUNTER POINTER HEIGHT PRESENTATION ON A HUD**
Aplin, J. E. and Wickham, G., GB RAE Tech Memo FS 21, 1975
- 249. A SIMULATOR STUDY OF THE VALUE OF SUPERPOSING FLIGHT DATA ON AN ELECTRO-OPTICAL DISPLAY USED FOR HIGH SPEED LOW LEVEL FLYING**
Oldfield, D. E. and Hammett, R. F., GB RAE Tech Memo FS 18, 1975
- 250. A SINGLE FAIL-PASSIVE AUTO-PILOT AND A HEAD-UP DISPLAY FOR CATEGORY THREE SMALL "A" APPROACHES AND LANDINGS**
Suisse, H., Test Pilot Avions Marcel Dassault, Breguet Aviation, Istres, France
At the start of the Mercure Program Study, it was made clear that the aircraft was to be capable of (French) category III approaches: i.e., 500 ft RVR associated with 50 ft decision height.
- 251. THE SINGLE TASK. A FLYABILITY IMPROVEMENT TO THE VISUAL LANDING AID**
Bateman, C. D., Sundstrand Co., Redmond, Wash., 1971

252. SMITH'S PROGRAMMABLE HUD

Ford, T. E., Panama Islander Flight International, Brazil's Aerospace Market, August 2, 1973

Discusses the flexibility of the HUD. Explains that to change the format of the display without change of hardware, the required symbology is first drawn and then converted into a computer program compiled in plain machine code, etc.

253. SOCIETY FOR INFORMATION DISPLAY

Winner, L., International Symposium and Exhibition, San Diego, Calif., Digest of Technical Papers, May 21-23, 1974

Papers dealing with various aspects of advanced display technology are included. Gas discharge display systems, video disk techniques, matrix-addressed panels, display duality and human perception, visual flight simulation, computer displays in an interactive system, and large area displays are covered. The subjects also include laser displays, holographic displays, 3-D displays, software and system tradeoffs, onboard vehicle route instructions, and collision avoidance systems.

254. SOLUTIONS TO PILOTING PROBLEMS BY MEANS OF HEAD-UP DISPLAYS FROM COLLIMATED INSTRUMENTS

Lami, R. and Beck, R. H., All-Weather Operations Panel, ICAO, Rept. No. AWOP-B10/16, August 19, 1970

The various flight parameters which are employed by the pilot to guide and control his aircraft during both visual and instrument flight conditions are discussed at some length. The differences between visual and standard instrument panel guidance are highlighted along with their respective limitations. The solution of those problems through the use of collimated instrument displays (HUD's) are described.

255. SOME DESIGN CONSIDERATIONS FOR HUD RECORDING

Snow, P. R., Proceedings of the Society of Photo-Optical Instrumentation Engineers, Anaheim, Calif., A76-24001 09-35, March 17-18, 1975

Some of the factors which should be considered in HUD recording design are presented in this paper. The location of the recording device relative to the pilot, HUD, and windshield is discussed, as well as the need for consideration of a recording capability early in the design stages of the HUD and the aircraft crew station.

256. SPECIFICATION OF HOLOGRAM LENS SYSTEM

Anonymous, Naval Air Development Center, Air Vehicle Technology Dept., November 20, 1972

257. STANDBY SIGHT FOR HEAD UP TUBES

Anonymous, Rank Electronic Tubes, Sidcup, England, BR-40536, AD-920-142L, April 1974

A requirement exists in a HUD technology for providing a standby sight for use by the pilot in the event of loss of the primary displays due to a defective CRT or an electronic failure. The aim is to make use of an optical port at the back of the CRT, by projecting an image from an auxiliary source external to the CRT onto the rear of the phosphor screen and provide a standby sight facility.

258. STANDBY SIGHT FOR HEAD-UP TUBES

Anonymous, Rank Electronic Tubes, Sidcup, England, AD-878-526L, November 1970

259. THE STATUS OF HUMAN PERCEPTUAL CHARACTERISTIC DATA FOR ELECTRONIC FLIGHT DISPLAY DESIGN

Burnette, K. T., Conference on Control Displays, AGARD-CP-96, Paris, France, October 1971

This article is a summary of some of the more interesting data obtained from a search and analysis of the human factors literature for human perceptual characteristic data relating to the design of individual electronic flight displays.

260. A STUDY OF REFLECTION PROBLEMS IN HUD

Kempston, R. A., GB RAE Tech Memo Avionics 96, 1972

261. A STUDY ON AIRCRAFT MAP DISPLAY LOCATION AND ORIENTATION

Baty, D. L., Wempe, T. E., and Huff, E. M., In MIT of the 9th Annual Conference on Manual Control, Ames Research Center, NASA, Moffett Field, Calif., 1975
Six airline pilots participated in a fixed-base simulator study to determine the effects of two horizontal situation display panel locations relative to the vertical situation display, and of three map orientations on manual piloting performance. Significant performance differences were found between wind conditions and among pilots but not between map locations and orientations. The results also illustrate the potential tracking accuracy of such a display.

262. STUDY ON TEAM PERFORMANCE OF CONTROLLING YS-11 AIRCRAFT

Hagihara, H., Aramaki, S., and Nagaswa, Y., Japan Air Self Defense Force, Aeromedical Lab., Vol. 16, June 1975

Motion-picture and tape-recorder studies were made of the performance and response of a pilot and copilot during takeoff, flight, and landing. The pilot and copilot responded simultaneously to 57 percent of in-flight visual information, and 33 percent of decision making, but continuous control and piloting action by the pilot was accompanied by discrete actions on the copilot's part. The frequency of responses to HUD and side panels, and accompaniment of speech utterances by related action, are noted.

263. SUMMARY OF VARIOUS ASTRONAUTICS ELECTRON DISPLAYS

Anonymous, Astronautics Corp. of America, Milwaukee, Wisconsin, February 13, 1976

264. THE SUNDSTRAND VISUAL APPROACH MONITOR (VAM) HUD

Short, D. C., Sundstrand Data Control, Inc., Redmond, Wash., August 1974
Summary of theories and specifications for Sundstrand visual approach monitor system.

265. A SURVEY OF LASER DISPLAY

Kennedy, D. W., Grauling, C. R., Devandy, A. J., and Wright, R. D., Rept. No. NASA SP-159, Cambridge, Mass., September 19-27, 1967

266. A SURVEY OF SIGHTING AND AIMING DEVICES

Hasselbring, H. H., Naval Avionics Facility, Rept. No. NAF1-TR-1557, AD-874-517L, July 1970

This report provides general information on past, present, and future airborne gunsights and aiming devices.

267. T-38 VISUAL LANDING AID STUDY

Odle, M. L., Bunker-Ramo Corp., Westlake Village, Calif., Rept. No. AD-769-397, IFC-TR-73-7, August 1973

The study of the Visual Landing Aid (VLA), a HUD of flightpath angle and flight-path, was conducted to determine whether the device was of assistance to the pilot in intercepting and maintaining a desired approach angle for visual approaches in the T38 aircraft. Sixty VFR approaches were flown using three approach conditions. The unaided manual condition provided baseline data for comparison purposes.

268. TACHISTOSCOPIC INVESTIGATIONS ON ELECTRONIC AND CONVENTIONAL COCKPIT DISPLAYS

Heinze, W., European Space Agency, Paris, France, Rept. No. DLR-FB-73-27, March 1974

In connection with investigations into the possible application of electronically produced data representation and flight guidance and control, a comparison of electro-mechanical and electronic indicating instruments was carried out by means of a tachistoscope. The results are noted in this report.

269. TC-121 AND OTHER HUD MIS-MATCH WITH RUNWAY

Terhune, G. J., Jr., Air Line Pilots Association, Wash., D. C., May 1976

270. THE TC-121 HUD: A SUPERIOR "INFORMATION PACKAGE" FOR THE PILOT

Goldstein, C., Israel ALPA, Rept. No. L75C231, February 1975

271. TECHNICAL SUMMARY, HUD 123

Anonymous Astronautics Corp. of America, Milwaukee, Wisconsin, September 5, 1973
General specifications and related drawings for two military HUD system to meet requirements for the A10 aircraft.

272. TOTAL COCKPIT IMPLICATIONS OF ELECTRO-OPTICAL DISPLAYS

Reising, J. M., AGARD Electro-opt. Systems, AGARD-LS-76, N75-26778 17-20, May 1975

The implications for using electro-optical displays to replace many of the electro-mechanical instruments are discussed. Early developments in electro-optical cockpits are reviewed and current research programs are discussed. The unique impacts of electro-optical displays in the design of both close air support and air superiority aircraft are examined in detail. The future of the electro-optical cockpit is discussed and conclusions reached to its visibility.

273. TRADE-OFF STUDY FOR A HEAD-UP DISPLAY IN NEW TECHNOLOGIES

Lewis, W. N., Withrington, R. J., Close, D. H., and Jacobs, R. S., Hughes Aircraft Co., Culver City, Calif., Rept. No. NADC-75320-30, November 1976

The application of new technologies to advancing the state-of-the-art in HUD is investigated. Advanced designs are proposed and tradeoffs conducted using various new display and optical technologies such as diffraction optics, fiber optics, and liquid crystals.

274. A TRUE 3D FLAT 2D DISPLAY

Lewis, J. D. and Walling, G. P., Guidance and Control Displays, AGARD-CP-96
A new display principle is described which promises to make available a true three-dimensional display or a multicolor, solid-state, flat-panel display. The advantages of presenting 3D information in a true 3D format are discussed.

275. THE TYPE 664 HUD WEAPON AIMING SYSTEM

Anonymous, AGARD-CP-167, N76-17107 08-06, December 1975

HUD systems incorporating general purpose digital computers are now in wide-scale operational service, and their effectiveness and reliability have been demonstrated in over 1,000,000 flying hours. Later developments of this type of system have expanded the role of the HUD computer; this report explains them.

276. UNDERSTANDING A ROLE FOR THE HEAD-UP DISPLAY IN ALL-WEATHER AIR TRANSPORT OPERATIONS

Anonymous, TP-301-II, Systems Technology, Inc., Mountain View, Calif., May 1974
A technical proposal is presented measuring the safety contribution of HUD for all-weather aircraft operations.

277. THE USE OF A HUD SYSTEM IN THE ENROUTE PHASE OF A TACTICAL MISSION

Wewerinke, P. H., National Aerospace Lab., NLR, Netherland, NLR TR 73081 L
A flight test program was conducted to investigate the effect of a HUD system on the effectiveness of the enroute phase of a tactical mission. This document gives the results.

278. THE USE OF IN-FLIGHT SIMULATION TO DEVELOP CONTROL SYSTEM AND DISPLAY REQUIREMENTS FOR CONVENTIONAL AND V/STOL AIRPLANES

Aiken, E. W., Hall, G. W., and Lebacqz, J. R., 2nd Advanced Aircravt Display Symposium, Calspan Corp., Buffalo, N.Y., April 23-24, 1975

279. THE USE OF RAY INTERCEPT CURVES FOR EVALUATING HOLOGRAPHIC OPTICAL ELEMENTS

Close, D. H., Applications of Geometrical Optics, Annual Technical Meeting, 17th, Seminar-in-Depth, San Diego, Calif., N62269-73-C-0388, August 27-29, 1973
The use of ray intercept curves is demonstrated in evaluations of the characteristics of wide-field-of-view holographic optical elements. Using for demonstration the example of a HUD system, it is shown that desired levels of system performance are achievable.

280. USE OF STEREOPSIS IN ELECTRONIC DISPLAYS: PART I--REVIEW OF STEREOGRAPHIC CHARACTERISTICS AND APPLICATIONS OF STEREO VIEWING SYSTEMS

Zamarin, D. M., Douglas Aircraft Co., Rept. No. MDC J 7084, Douglas Aircraft Co., December 1976

This report reviews the design, application, and evaluation of electronic stereo viewing systems. A brief description of the characteristics and mechanisms of stereoscopic perception is provided followed by a review and evaluation of various stereo system techniques.

281. THE VALUE OF A HEAD-UP DISPLAY WHEN LANDING A LARGE AIRCRAFT

Armstrong, B. D., Royal Aircraft Estab., Farnborough, England, Rept. No. RAE-TR-69236, AD-865-259L, October 1969

This report undertakes a critical review of the situations in which a collimated HUD of cockpit information might be useful to the pilot of a large aircraft during the approach and landing maneuver.

282. VELOCITY VECTOR AND ENERGY MANAGEMENT--A SENSIBLE WAY TO FLY AEROPLANES
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Cornsweet, T., Academic Press, New York, 1970

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Knowles, W. B. and Wulfeck, J. W., Ames Research Center, NASA, CR-114361, Contract No. NAS 12-2262, June 30, 1971
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Gold, T. and Perry, R. F., Sperry Rand Corp., Great Neck, N. Y., JANAIR 700407, AD-741-218, March 1973

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291. WARNING . . . APPROACH LIGHTS IN SIGHT

DeCelles, J. L., Burke, E. J., and O'Brien, J. E., Air Line Pilots Association All-Weather Flying Committee

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Bert, A. A., Hughes Aircraft Co., May 1976

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Gartner, W. B., McTee, A. C., SRI International, Menlo Park, Calif., Report No. FAA-RD-77-166

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